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JOHN T. LARSEN

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by

John T. Larsen

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
MATERIAL SCIENCE

United States Naval Postgraduate School
Monterey, California
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AN X-RAY METHOD FOR FOLLOWING THE PRECIPITATION PROCESS IN POLYCRYSTALLINE ALUMINUM-COPPER

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MASTER OF SCIENCE
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from the
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ABSTRACT

An experimental study has been made of the feasibility of following the precipitation process in a polycrystalline aluminum-2½% copper alloy. The intermediate structures formed during ageing have previously been determined by single crystal methods to pass through the following sequence:

$$G.P.[1] \rightarrow G.P.[2] \rightarrow \theta' \rightarrow \theta$$

The sequence of structures was followed by analysis of the diffractometer line profile of the $\alpha(200)$ peaks. The experimental profiles were corrected for instrumental broadening by the Stokes method. One-dimensional Patterson projections of the electron density distribution in the alloys were synthesized from the corrected profiles.

The complete sequence of intermediate precipitates could not be realized in this investigation. However it was possible by this method to distingish between the G.P. [1] and θ' structures by observing the height and shift of the Patterson function origin peaks.

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ACKNOWLEDGEMENTS

The writer is indebted to Professor John R. Clark, Department of Material Science and Chemistry, for his guidance and encouragement given during the course of this investigation.

1. Introduction.

The phenomenon of precipitation hardening holds great commercial interest. It is a method of enhancing the mechanical properties of a metal without resorting to other processes such as work hardening, dispersion hardening or a martensitic type transformation. It eliminates the concern regarding the hardenability of a metal. Metal parts may also be formed or fabricated in a soft condition and then hardened by a relatively simple ageing treatment while retaining excellent dimensional stability. One example of the importance of precipitation hardening is its application to aluminum alloys which has resulted in a great number of usable high strength materials.

The mechanism of precipitation hardening is not at all simple. The most basic concept involves the formation of a stable phase dispersed throughout a matrix. This does not include dispersion hardening, which is due to the presence of a second phase dispersed in the matrix. However, it is not a precipitation process. Even in the basic concept of precipatation there are constraints imposed on the nucleation and growth of such a phase because it is being formed in a solid solution. In general, the process is much more complicated than this. It varies with each alloy system but usually involves the precipitation of a metastable phase, which later gives way to a stable one. There may be as many as three intermediate stages before the stable precipitate is formed. The intermediates may or may not be true phases, depending on the alloy system.

The intermediate stages hold great interest. In many alloy systems these intermediates have the greatest influence on mechanical properties, and the formation of a stable precipitate results in a

decrease in hardness and strength.

The Al-Cu alloy represents an ideal system in which to study the age-hardening process. It is representative of many systems for it displays both substitutional and displacement disorder during ageing. The copper atoms have a greater scattering factor and a smaller radius than the aluminum atoms (f_{Cu}/f_{Al} = 29/13 and 2.56 Å compared to 2.86 Å). The difference in atomic size results in the displacement disorder while the greater scattering factor of copper allows its effects to be detected by x-ray analysis.

The age-hardening system in Al-Cu has been studied more than any other. As a result its sequence of structures is known in considerable detail.[1]

The mechanism of the decomposition of the quenced supersaturated solid solution shows four different stages whose relative roles depend strongly on the annealing temperature. In general the sequence may be represented as follows:

$$G.P.[1] \rightarrow G.P.[2] \rightarrow \theta' \rightarrow \theta$$

Two stages, θ and θ', correspond to true precipitates of composition $CuAl_2$, where θ is the equilibrium phase. The G.P. refers to a "Guinier-Preston zone", which may be defined as a region rich in solute atoms which is formed on certain planes in the solvent matrix and retains what is essentially the structure of the matrix. G.P.[1] is a copper rich region of plate-like shape formed on $\{100\}$ planes of the aluminum matrix whose maximum size is a few atomic planes thick and up to about 100 Å in diameter. G.P.[2] displays features

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[1]J. M. Silcock, T. J. Heal and H. K. Hardy, J. Inst. Metals 82, 240-242 (1953).

of a zone and a true phase. As these platelets reach a thickness of about 30 Å they become unstable and dissolve. They may be considered as having a lattice similar to that of the aluminum matrix. To a first approximation it is merely a superlattice of aluminum, tetragonal with $c/a = 2$ where a is the parameter of aluminum.

The above structures do not necessarily evolve from one another in sequence, but two (or more) may occur simultaneously in the same specimen. The conditions have been determined in which the three metastable phases and the equilibrium phase appear as a function of time and temperature for different concentrations of Cu in Al.[2]

A variety of x-ray techniques have been used in the numerous precipitation investigations. Single crystals have generally been employed using both white and monochromatic radiation. Some work has been done using normal powder methods. The small angle scatter method has been applied with great success by Guinier.[3] The techniques using single crystals and monochromatic radiation have advantages of ease and certainty of interpretation in terms of a reciprocal lattice plot, but require sophisticated equipment and precise experimental technique. Some of the results obtained by the above methods have recently been confirmed by electron microscopic photographs.[4] The use of an x-ray diffractometer in the analysis of polycrystalline specimens is attractive because of the relatively simple procedures involved and the possible extension of

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[2] Ibid., pp. 243-45.

[3] A. Guinier, Ann. Phys. 12, 161 (1939).

[4] G. Thomas, Transmission Electron Microscopy of Metals, pp. 236-248.

the technique to precipitation studies in commercial alloys. Hence, it is the purpose of this investigation to follow the ageing process in a polycrystalline Al-4%Cu alloy by means of a diffraction line shape analysis and Patterson projection of the electron density distribution within the alloy.

The data necessary to form a Patterson function is available from a diffraction line profile, as is shown below. However, a true line profile must first be obtained by correcting the observed profile for instrumental broadening, due mainly to the slight spread of wavelengths in the incident radiation. A method has been derived by Stokes using the convolution theorem of mathematics to correct the experimental line shape without any prior assumptions concerning the corrected line shape.[5] The method consists essentially of obtaining the Fourier coefficients for the broadened and reference curves, operating on these coefficients (termed unfolding), and then synthesizing the corrected curve from the unfolded coefficients. This technique eliminated broadening due to K_α doubling as well as other forms of broadening.

It has been shown that the true line profile is proportional to the Fourier transform of the square of the absolute magnitude of the structure factor, $|F_{hkl}|^2$.[6] The structure factor F_{hkl}, in general a complex quantity, represents something real about a crystalline material for it is the Fourier transform of the electron density in

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[5]A. R. Stokes, Proc. Phys. Soc. London 61, 382 (1948).

[6]A. J. C. Wilson, X-Ray Optics, p. 107.

the material.[7] Experimentally only $|F_{hk\ell}|^2$ is determined which yields no information concerning its phase. If the phase relations could be determined experimentally there would be no problem in finding the arrangement of atoms in any crystal, no matter how complicated. Of the methods proposed to circumvent the phase problem, the Patterson function has emerged as the most powerful and adaptable. This function is a Fourier series whose coefficients are $|F_{hk\ell}|^2$.[8] If one considers the Fourier coefficients $|F_{hk\ell}|^2$ as derived by forming products of each Fourier coefficient $F_{hk\ell}$ with its complex conjugate, the electron density function can be derived directly from the Patterson function. The Patterson function is essentially a display of all the vector lengths between atoms of a unit cell. All the vectors of one length will then appear as a peak in this display. Since the reverse vectors are also displayed, it is necessary to sort out the duplicated peaks in order to arrive at the electron density function.

2. Alloy preparation.

The Al-4%Cu (by weight) alloy was prepared using 99.99% ingot Al and 99.94% Cu shot. The aluminum was first melted in an induction heated graphite crucible, and then the copper shot was added. The molten metal was held between 700° and 720°C for 45 minutes to ensure complete solution of the copper. The alloy was cast into a flat rectangular zirconia boat, preheated to 700°C, and allowed to solidify at room temperature. The ingot thus formed weighed 125 grams,

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[7]A. Guinier, X-Ray Diffraction, p. 92.

[8]M. J. Buerger, Vector Space, pp. 5-10.

measuring approximately 4" x $2\frac{1}{4}$" x $\frac{3}{8}$".

Microscopic examination of the ingot revealed a large grained structure containing intergranular theta phase and no evidence of undissolved copper.

The ingot was homogenized at 542°C for 24 hours and furnace cooled. Grain refinement was accomplished by cold rolling and recrystallizing at 600°C for one hour. The amount of reduction per pass through the rolls was limited to about 20% due to work hardening, so the refinement treatment had to be repeated three times, resulting in an ingot .17" thick, and containing equiaxed small grains with finely divided theta phase dispersed throughout.

Eight hardness specimens were cut from the ingot, each being about 1.75" x .5" x .17" in size. A hole was drilled in one corner of each specimen and top and bottom surfaces were smoothed on no. 0 and no. 3/0 metallographic paper.

3. Solution treatment and age hardening.

The eight specimens were strung on a wire with a $\frac{1}{2}$" separation to ensure rapid heat transfer both on heating and quenching. They were solution treated in a salt bath for six days at 536°C, which is about 36° above the solid solubility of 4% copper in aluminum.[9] Following the solution treatment the specimens were quenched in room temperature water, and the as quenched hardness was taken immediately on one specimen. The surface irregularities caused by the salt bath on the remaining specimens were removed by lightly

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[9] M. Hansen, Constitution of Binary Alloys, p. 84.

polishing on no. 0 and no. 3/0 paper. They were then suspended in an oil bath at 165°C for ageing. The as quenched hardness specimen was aged at room temperature.

Microscopic examination of the as quenched hardness specimen following solution treatment revealed a small amount of undissolved theta phase in the structure. A lattice parameter measurement on the α(422) diffraction peak of this specimen indicated that about $2\frac{1}{2}\%$ of the copper had gone into solution. The small amount of undissolved theta would have no effect other than to reduce the peak hardness obtained during ageing.

4. Diffraction procedure.

As each specimen reached its respective ageing time, it was quenched in room temperature water and hardness readings were taken immediately. No less than six readings were taken on both sides to ensure a good average. The surfaces were then given a rough electropolish to remove the oxide layer and to ensure that the surface was as nearly a true representation of the bulk of the specimen as possible. Chemical macro-etching was not used due to its preferential removal of copper from the alloy.

The α(200) peak of each specimen was recorded using a Norelco x-ray diffractometer with Ni filtered $CuK\alpha$ radiation. The diffracted radiation was counted by a xenon proportional tube in conjunction with a pulse height analyzer set to pass the central 90% of the pulse distribution.

The reference peak for the Stokes' unfolding was obtained from a recrystallized specimen of the pure ingot aluminum. It was possible

to get a well resolved $K\alpha$ doublet for the (200) peak from this specimen.

5. Treatment of data.

The intensity of each diffraction peak was recorded as a function of 2θ. Due to the sharpness of the reference peak it was necessary to use an interval of $.0125^\circ\ 2\theta$ between points to describe the peak by a smooth curve. It was possible to use a point interval of $.025^\circ\ 2\theta$ to describe the broadened peaks. A total interval of 1.8° was used on all broadened peaks except the as quenched and aged one day specimens, where it was possible to use slightly shorter intervals due to their narrowness. The maximum value of the diffraction peak was centered in the total interval in all cases.

The unfolding and Patterson function synthesis calculations were performed by the U. S. Naval Postgraduate School's CDC 1604 electronic computer. The diffraction intensity data was punched onto computer cards for input to a Fortran program developed by Prof. J. R. Clark, Dept. of Material Science and Chemistry, to execute the above calculations.

6. Experimental results.

The hardness/ageing time curve for the specimens aged at 165°C is shown in Fig. 1, page 9. The specimen aged at room temperature for 65 days attained a Rockwell "F" hardness of 77.4.

The lattice parameter of the as quenched specimen was 4.044 Å, which corresponds to $2\frac{1}{2}$ weight per cent copper in solution. The specimen aged at 165°C for one and two days retained this same lattice parameter. The lattice parameter of the specimens aged for five days

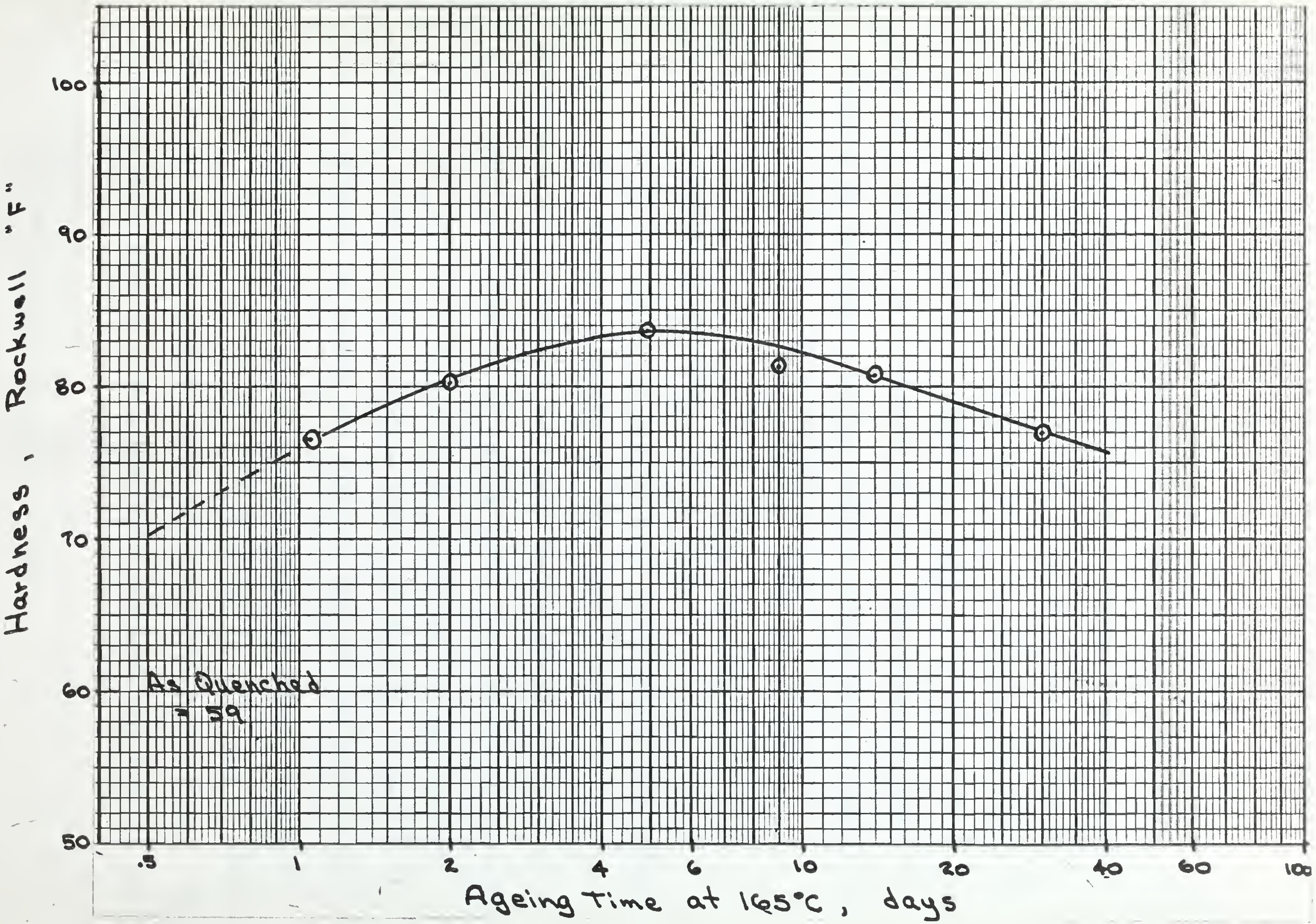

Fig. 1. Hardness/Ageing Time Curve

and longer was 4.049Å, which is the same as that of pure aluminum. The as quenched specimen retained the same lattice parameter on ageing at room temperature for 65 days.

The Patterson functions for the artificially and naturally aged specimens are shown in Appendix I on both a small and large scale. The ordinate is P(w), where $\vec{w}$ is the interatomic vector length. The vector between any two atoms in the crystal always has its tail at the origin in the Patterson function. The abcissa then represents the magnitude of $\vec{w}$ as it ranges from zero to "a", the lattice parameter of aluminum, in increments of .01a. The Patterson functions displayed in Appendix I are the one-dimensional projections of the electron density in the $\langle 100 \rangle_{Al}$ direction.

7. Discussion of results.

The lattice parameter and hardness measurements were used to confirm the structures present at each ageing time. The lattice parameters were determined with only sufficient precision to detect any changes as a function of ageing time. The structures contained in each specimen were determined by comparing the experimental hardness curve with the hardness curves of Silcock, et al.[10] It was not possible to obtain the complete sequence of intermediate precipitates on ageing at 165°C since only 2½% copper went into solution. Initial ageing at 165°C produces G.P.[2] and θ' simultaneously, while at peak hardness (five days) θ' predominates. The specimen fully aged at room temperature contains only G.P.[1] since

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[10]Silcock, _et al._, _op. cit._, p. 243.

the precipitation process does not progress beyond this point in naturally aged specimens.[11]

Lattice parameter measurements confirmed that the above structures were present. A constant value of parameter is characteristic of the G.P. zones.[12] It was observed that the parameter remained constant during natural ageing. The parameter also remained constant through two days ageing at 165°C, indicating that G. P.[2] was present during this time. At five days ageing the parameter had relaxed to the pure aluminum value. Hence θ' became the predominant intermediate at this time.

When comparing the Patterson origin peaks, Appendix I, Figs. 4 through 11, it is observed that the as quenched and naturally aged specimens have peaks exactly at the origin while those of the artificially aged specimens are shifted slightly. Also the origin peak for the naturally aged specimen is roughly twice the magnitude of all the others. It has been shown that the Patterson peak height is not a true measure of the product of the number of electrons, Z_1Z_2, contained in the two atoms separated by the vector that corresponds to the peak.[13] The peak height is directly proportional to Z_1Z_2 but inversely proportional to the sum of the cross-sections of the electron density peaks for a one-dimensional Patterson peak. Therefore a high Patterson peak is not necessarily due to two heavy atoms. The height also depends on the product of the electron

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[11] Ibid.

[12] A. Guinier, Solid State Physics, Vol. 9, p. 341.

[13] Buerger, op. cit., p. 26.

densities of the atoms in the pair.

The copper atom has a greater electron density than aluminum. Copper contains 29 electrons compared to 13 in aluminum and is 11% smaller in atomic size. Hence the presence of copper in an atom pair would substantially increase the Patterson peak height for that pair. In a specimen fully aged at room temperature a large fraction of the copper atoms are assembled in the G.P. zones, which are a few atomic layers thick and are on the average less than 100Å apart.[14] When looking perpendicular to the zones in the $\langle 100 \rangle_{Al}$ direction there would be a certain number of vectors of length "a" between atom pairs containing one or two copper atoms. There would be a smaller number of like vectors in the as quenched specimen, which is assumed to be a random substitutional solid solution of copper atoms in the aluminum matrix. The number of such vectors would also be less in the artificially aged specimens, which initially contained G.P.[2] and θ' and later only θ'. This can best be shown by considering the accepted structure of θ', Fig. 2, page 13. The θ' structure is tetragonal with parameters a = 4.04 Å and c = 5.8 Å, and the axes are parallel to the $\langle 100 \rangle_{Al}$ directions.[15] Only one of the three possible orientations of θ' is shown in Fig. 2. When all three orientations are considered together, only two produce copper atom separations of 4.04 Å in the $\langle 100 \rangle_{Al}$ direction. Where G.P.[2] and θ' occur together the copper atoms are shared between them and the total number available to share in atom pairs 4.04 Å apart is less

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[14] A. Guinier, Solid State Physics, p. 341.

[15] Silcock, et al., op cit., p. 242

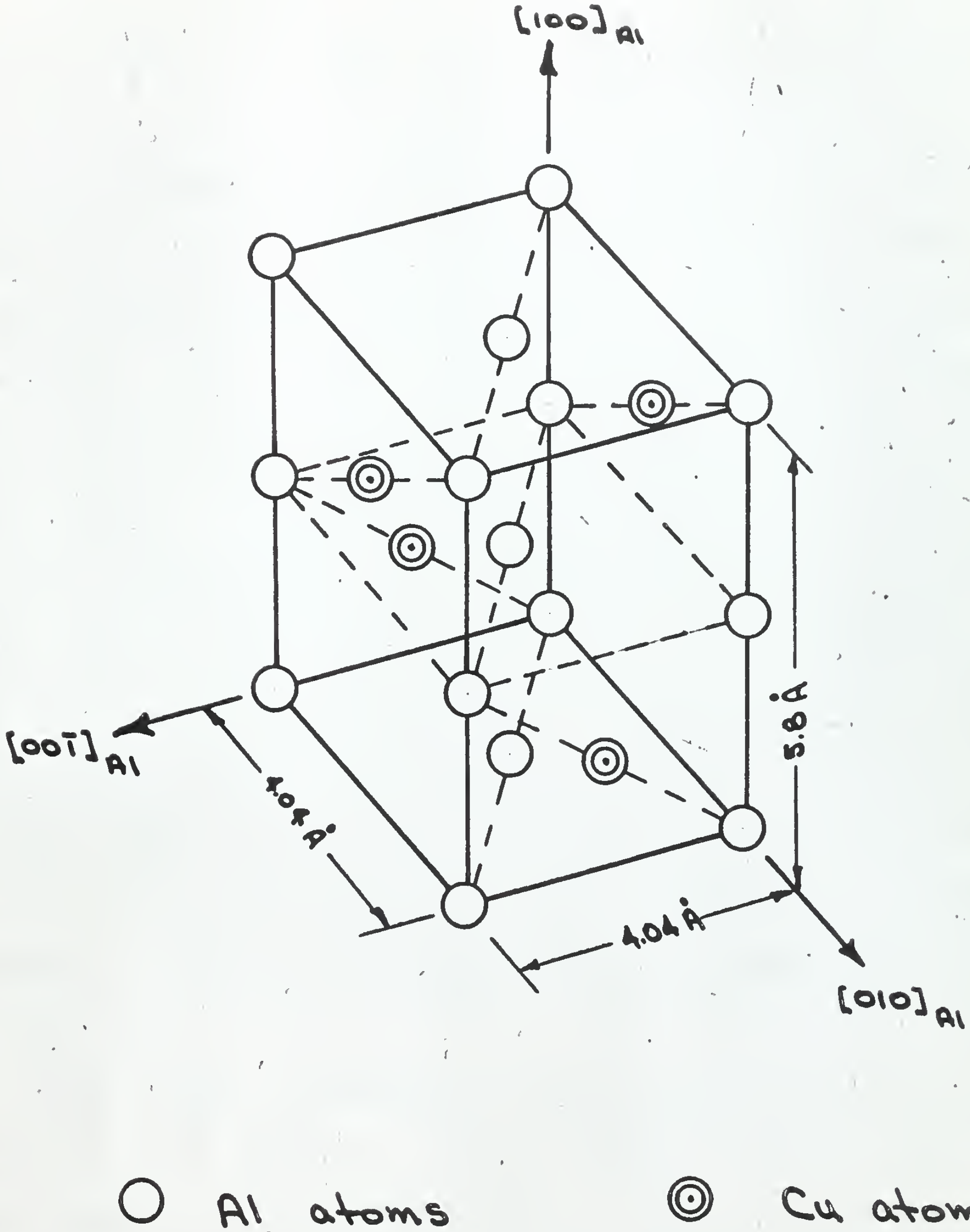

Fig. 2. Structure of θ′

than in the naturally aged specimen. This is also true when only θ' is present. Hence one would expect G.P.[1] zones to produce higher Patterson origin peaks than the other intermediate structures.

As seen in Appendix I the left origin Patterson peaks occur at $\vec{w}$ values slightly less than "a" for all artificially aged specimens. This shift is real and is not due to an error in calculation or plotting of the Patterson function. The peak is at .98a for one days ageing and at .99a for longer ageing times. This is best explained by considering the matrix distortion due to each of the intermediate precipitates. When a copper atom is substituted for an aluminum atom the matrix lattice contracts locally due to the smaller atomic size of copper. All three intermediate precipitates are coherent with the aluminum matrix. This coherency between matrix and precipitate lattices produces distortions in the matrix removed from the precipitate interface. The extent of the matrix distortion depends on the size and shape of the precipitate particle. Thus when G.P.[1] zones are formed in their thin disc shape the lattice distortions are small and do not extend far from the interface. The average cell parameter is then that of the matrix and the Patterson peak remains at $|\vec{w}| = a$.

When G.P.[2] is present the lattice distortions are more extensive than those due to G.P.[1], since the G.P.[2] zones are thicker and have larger diameters. The distortions due to θ' are also extensive because of the θ' c parameter of 5.8Å. Thus when G.P.[2] and θ' are present together after ageing one day the lattice is distorted by their combined effects and the Patterson peak occurs at $|\vec{w}| = .98a$. As the G.P.[2] zones dissolve and θ' grows with longer ageing times the

lattice distortion decreases and is due to θ' alone at peak hardness of five days.

In Appendix I, Figs. 12 through 19, are shown the Patterson functions on a large scale. In general, the number of resolved peaks increases as the ageing time increases. This is due to the increasing number of harmonics used in the synthesis of the Patterson function. The number of harmonics used in each case is determined by the point at which the coefficients of the broadened curve have decreased to a small value and those of the reference curve still have an appreciable value. The use of higher harmonics beyond this point results in a greater uncertainty in the coefficients of the corrected curve.[16] The intermediate peaks in the above Patterson functions are all quite small compared to the origin peaks. The resolution presented by the intermediate peaks is considerably greater than the 1.5 to 2Å expected using x-radiation of 1.542Å wave length. Thus the fine detail is false and is only a result of the harmonic analysis. No information concerning atomic positions can be gained from it. It is observed that the fine details of the Patterson functions for five days ageing and longer are essentially the same indicating that the line profiles are very nearly the same.

8. Conclusions and recommendations.

The scattered intensity distribution in reciprocal space for the aluminum-copper alloy is shown in Fig. 3.[17] The scattering

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[16] Stokes, op. cit., p. 389.

[17] A. Guinier, Solid State Physics, p. 339.

streaks around the nodes of the reciprocal lattice are due to the destruction of the strictly periodic electron density distribution in the crystal. This destruction is caused by the G. P. zones.

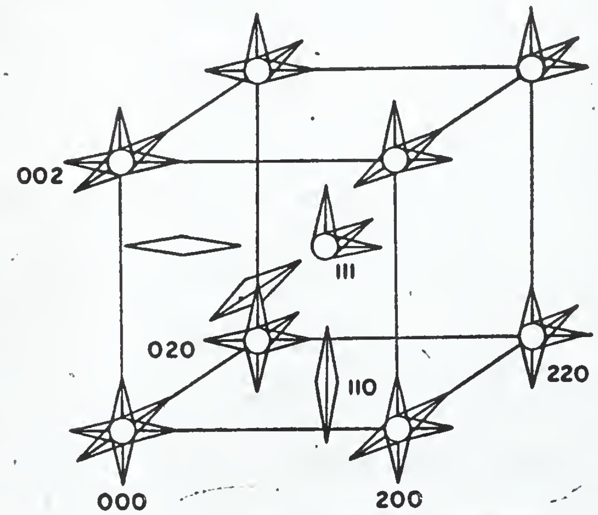

Fig. 3. Scattering in the reciprocal space of Al-Cu.

The streaks pass precisely through the nodes of the matrix and along the $\langle 100 \rangle$ rows of the reciprocal lattice. The fact that the G.P. zones distort the matrix lattice causes the scattering streaks to appear only on the high-angle side of the reciprocal lattice nodes.

It was anticipated that the diffuse streaks about the nodes would contribute to the diffraction process in a distinctive way. It should be possible to differentiate G.P.[1] from G.P.[2] since the length of the diffuse streaks are related to the size of the zone. This distinction could not be realized in the present investigation as G.P.[2] zones were not obtained by themselves on ageing. However

it was possible to distinguish G.P.[1] from θ' by observing the height and shift of the Patterson origin peak.

The amount contributed to the diffraction profile by the diffuse scattering streaks is uncertain. It is possible that the broadening of the profile due to instrumental factors, which were corrected for, is greater than that resulting from the diffuse streaks. However, since the instrumental broadening remains constant with ageing the profile changes due to the diffuse scattering streaks could be detectable. The thermal vibrations of the atoms about their average position in the crystal also produce anisotropic diffuse diffraction effects about the nodes of the reciprocal lattice. The thermal diffuse scattering is related to the elastic properties of the crystal, which certainly change during ageing. Hence, the changes in thermal scattering should also contribute to the line profile changes during ageing. The amount contributed and the best means of detecting it is a difficult problem to analyze quantitively. There has been no attempt in this investigation to do so.

There are several ways in which the application of this method of analysis could be improved. The use of monochromatic x-rays would eliminate the profile broadening due to the spectral spread of the incident beam. In order to observe the effect of each intermediate precipitate on the line profile it is necessary to have them existing separately in the alloy. The transition in the aluminum-copper system from G.P.[1] $\rightarrow$ G.P.[2] could best be observed by ageing a 4% copper alloy at 110°C, and from G.P.[2] $\rightarrow \theta'$ by ageing the same alloy at 190°C. The complete intermediate sequence could be achieved with definite separations in structures by ageing a 4.5% copper alloy at 130°C but would require ageing times of about 400 days.

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APPENDIX I

PATTERSON PROJECTIONS

The Patterson functions for the naturally and artificially aged specimens are shown on a small scale in Figs. 4 through 11, and on a large scale in Figs. 12 through 19. The ordinate is P(w), where $\vec{w}$ is the interatomic vector. The abcissa represents the magnitude of $\vec{w}$ as it ranges from 0 to "a".

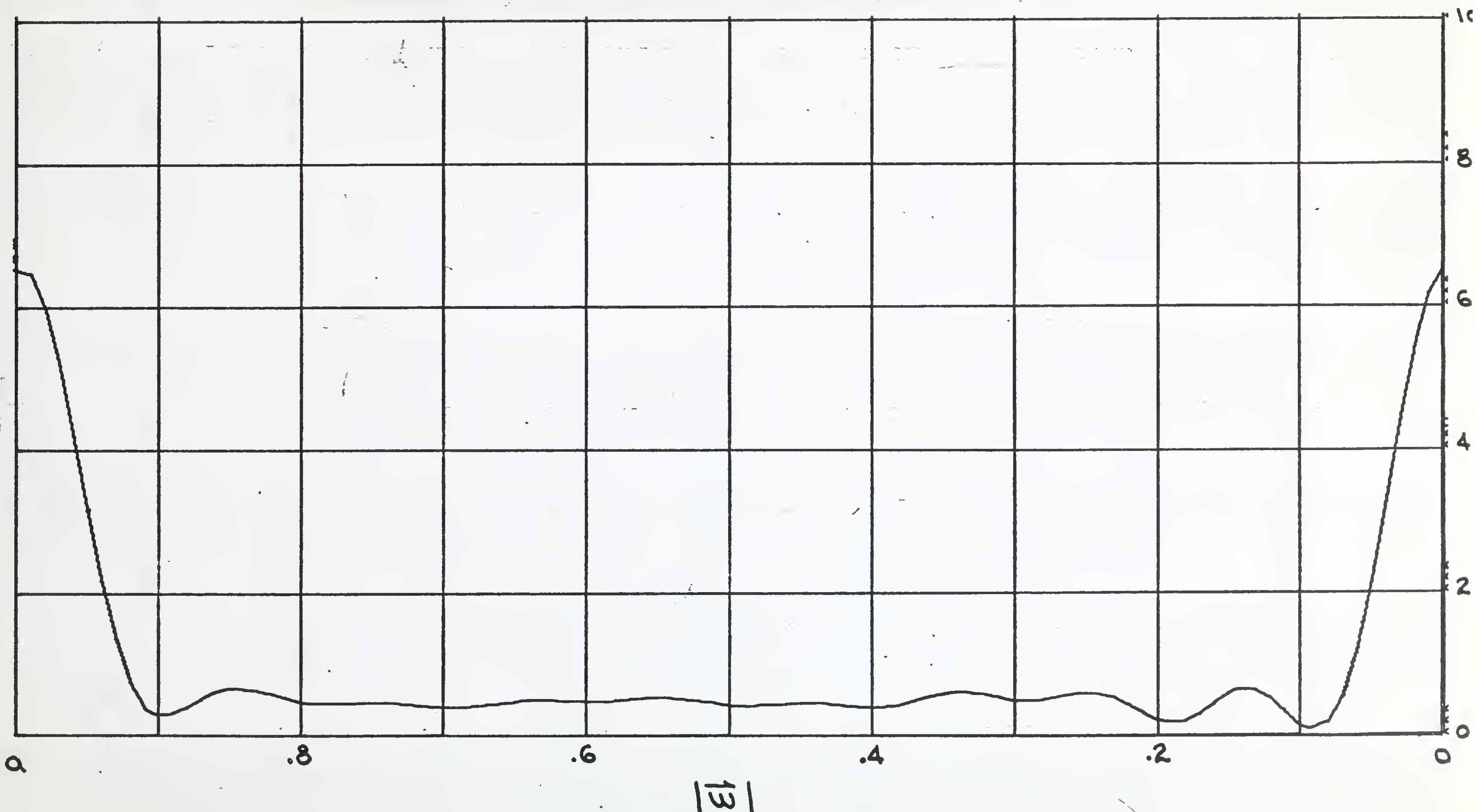

FIGURE 4. Patterson Function, As quenched specimen

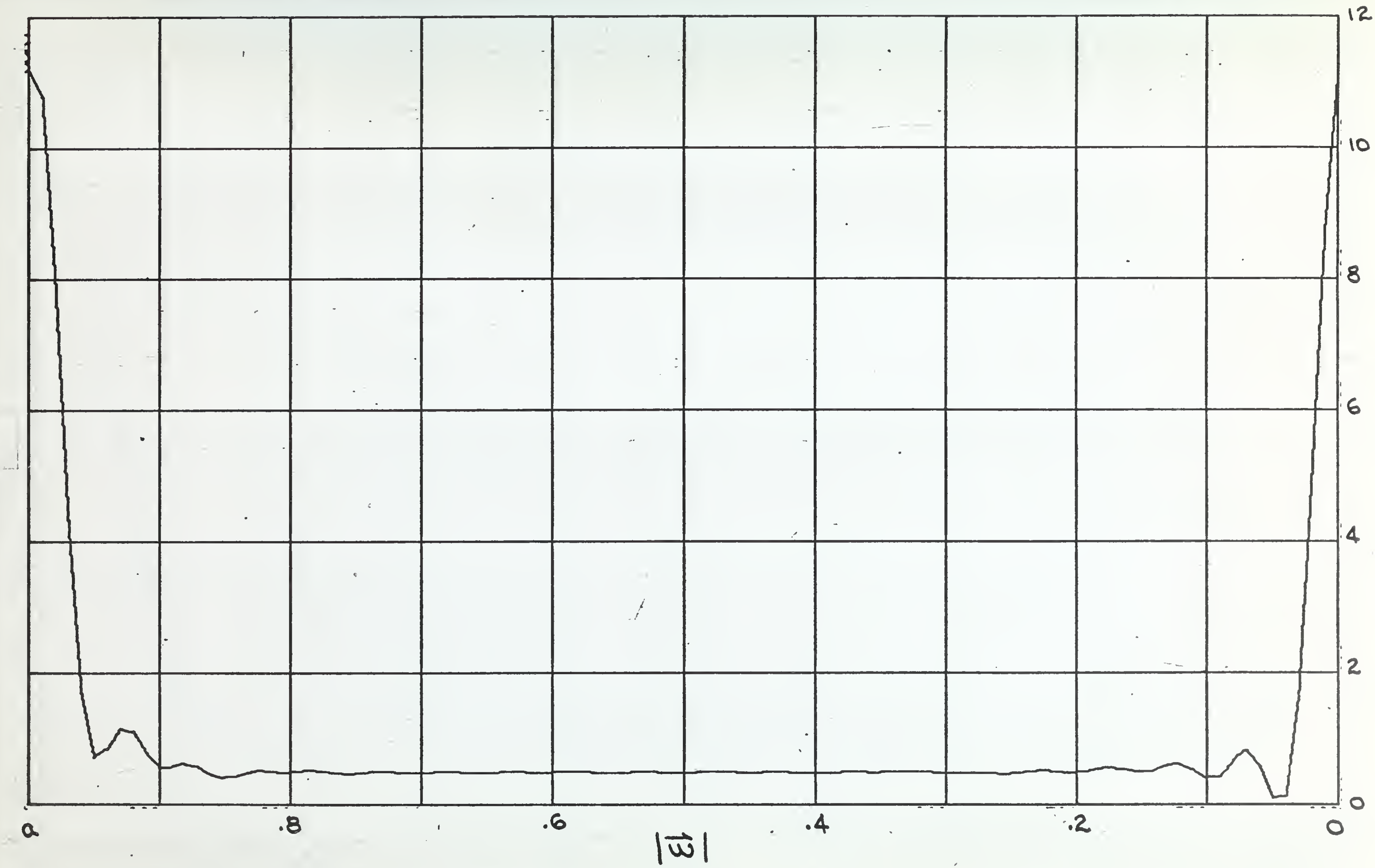

FIGURE 5. Patterson Function, aged 65 days at room temperature

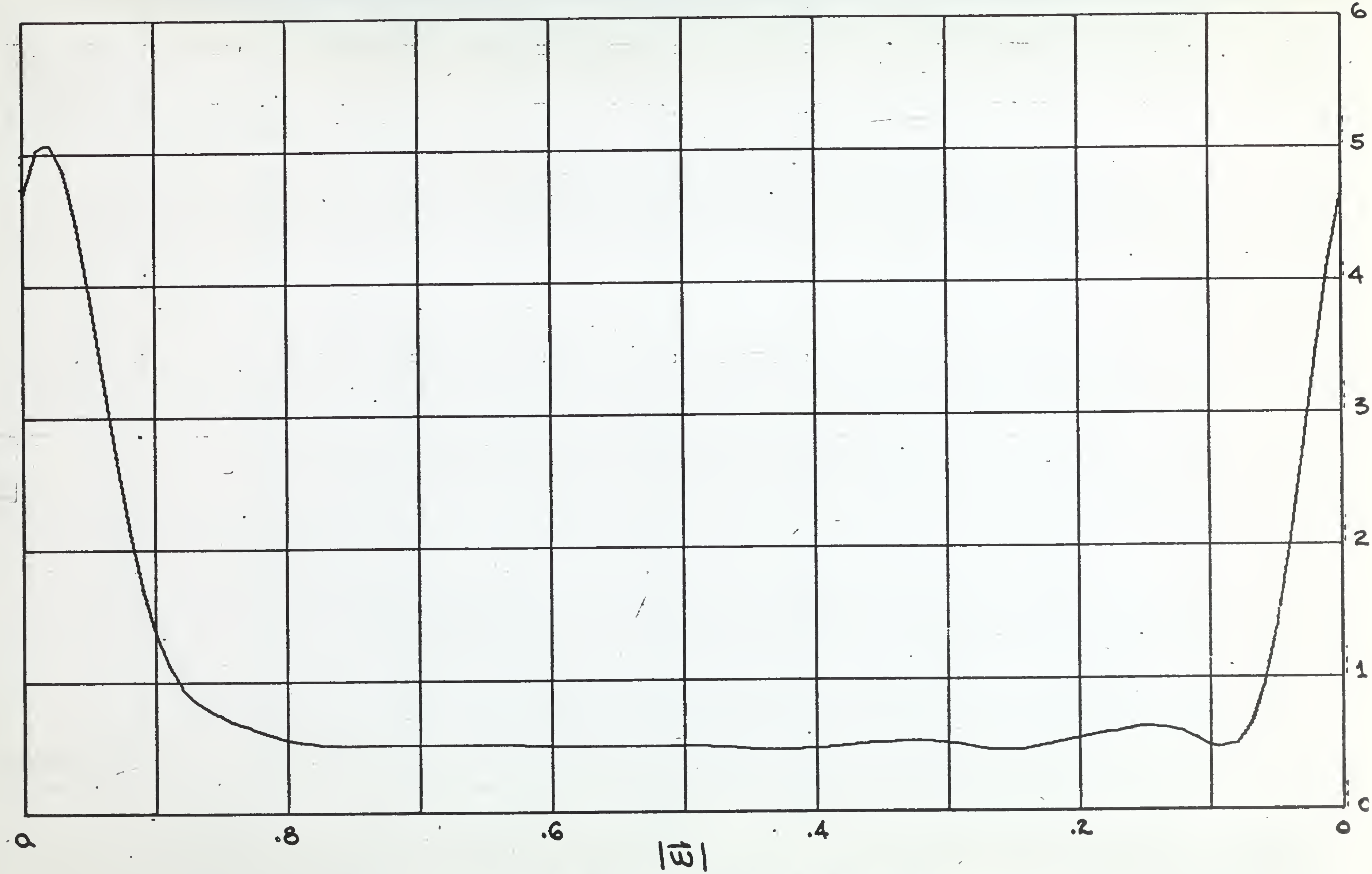

FIGURE 6. Patterson Function for specimen aged 1 day

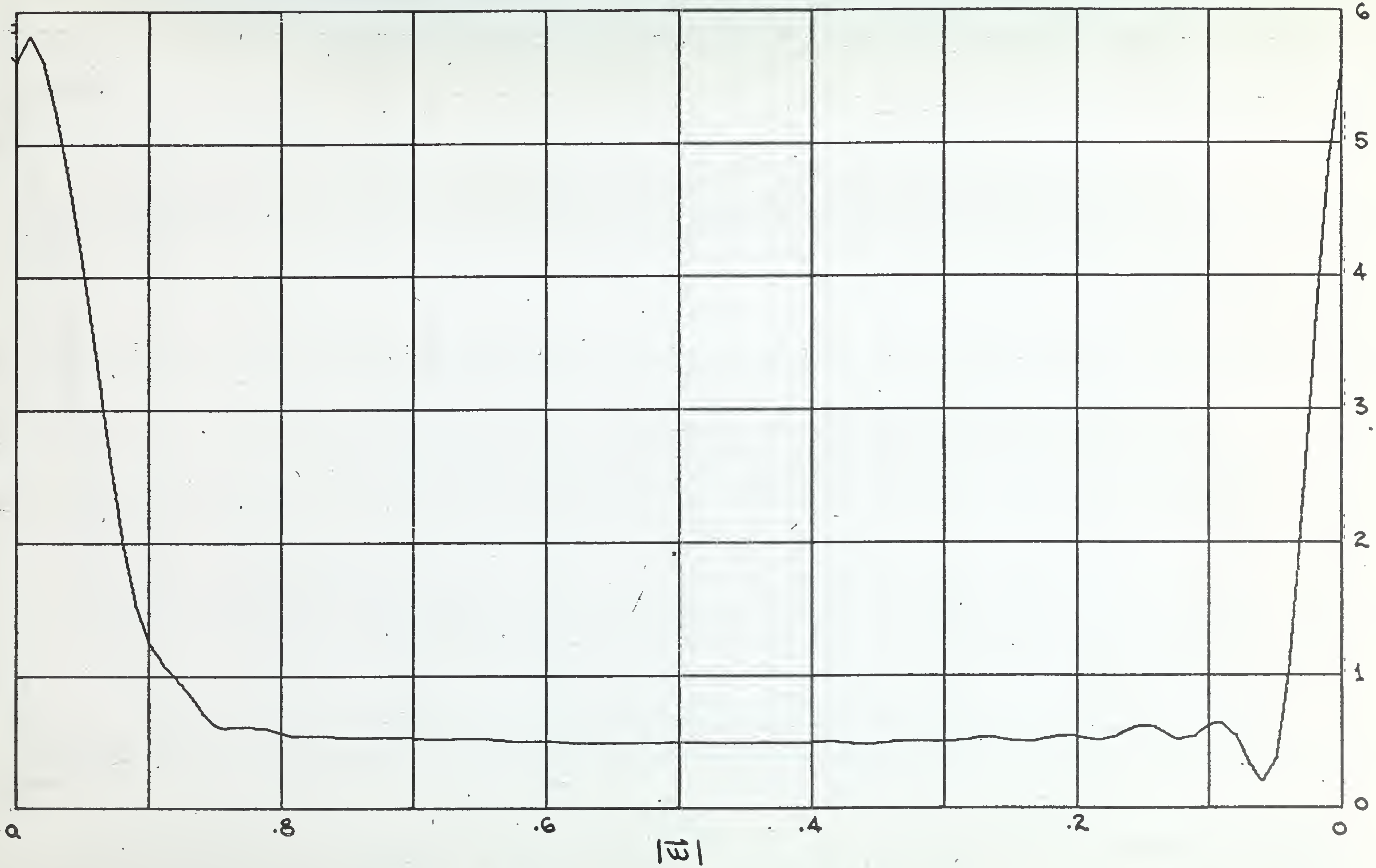

FIGURE 7. Patterson Function for specimen aged 2 days

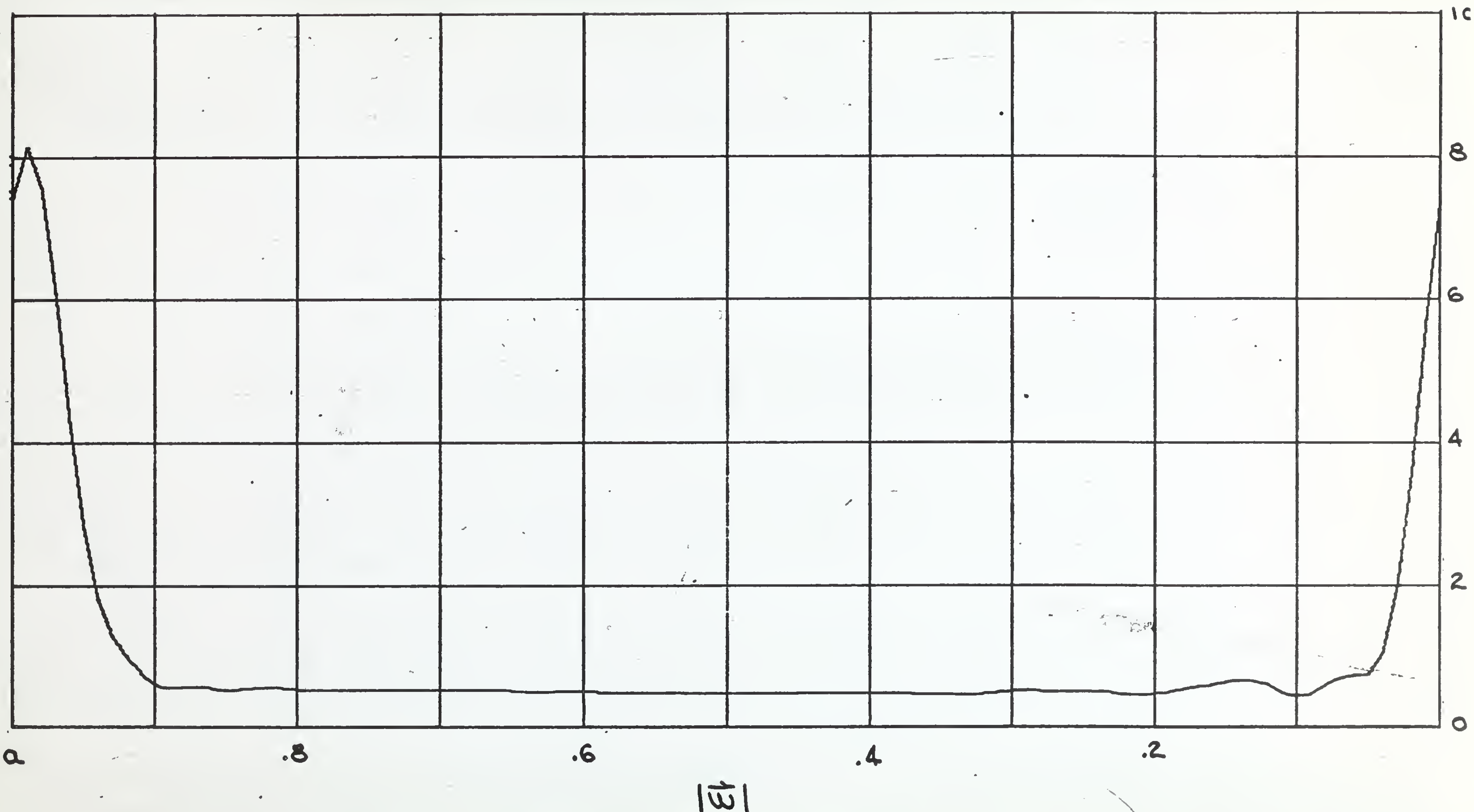

FIGURE 8. Patterson Function for specimen aged 5 days

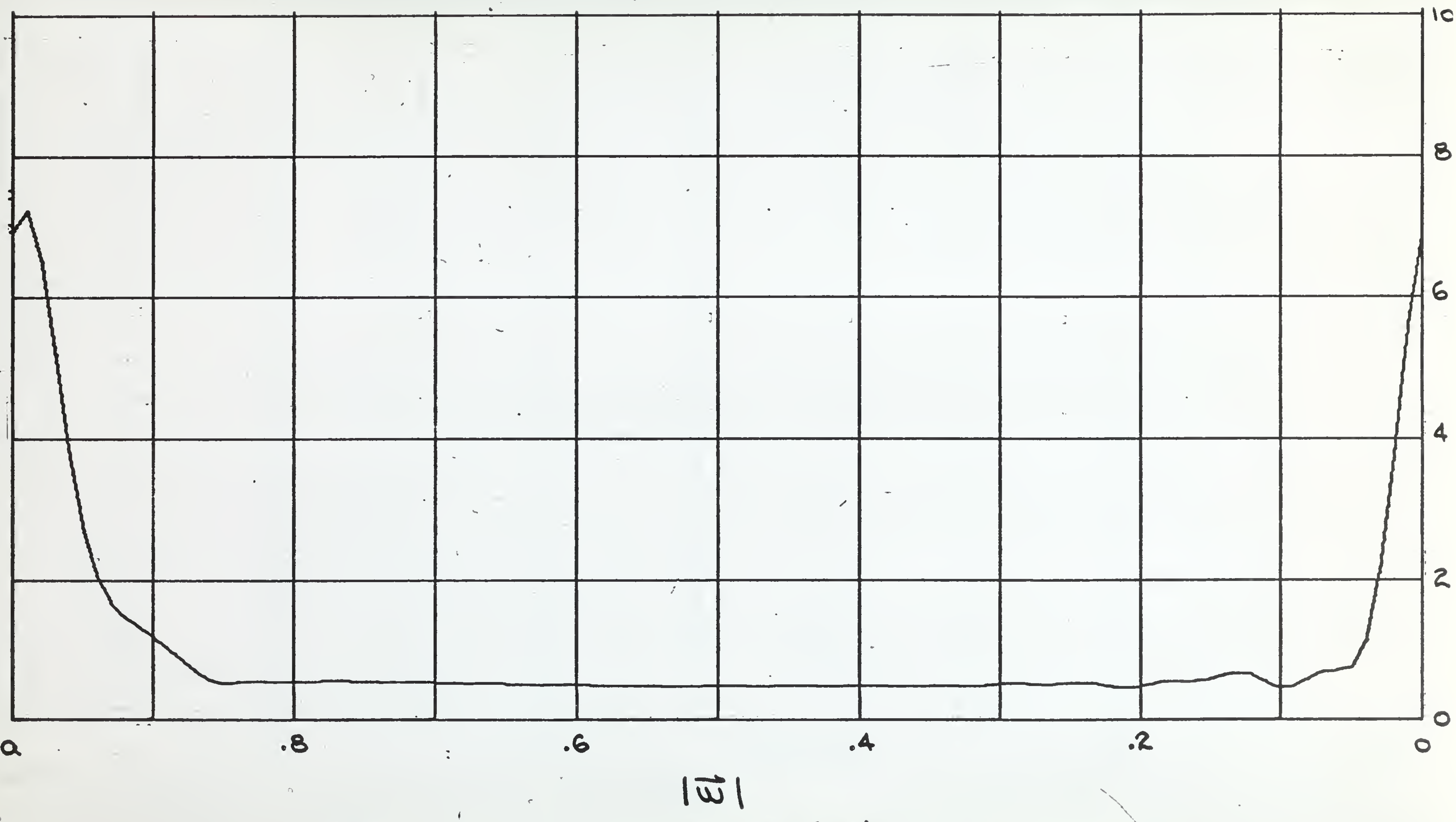

FIGURE 9. Patterson Function for specimen aged 9 days

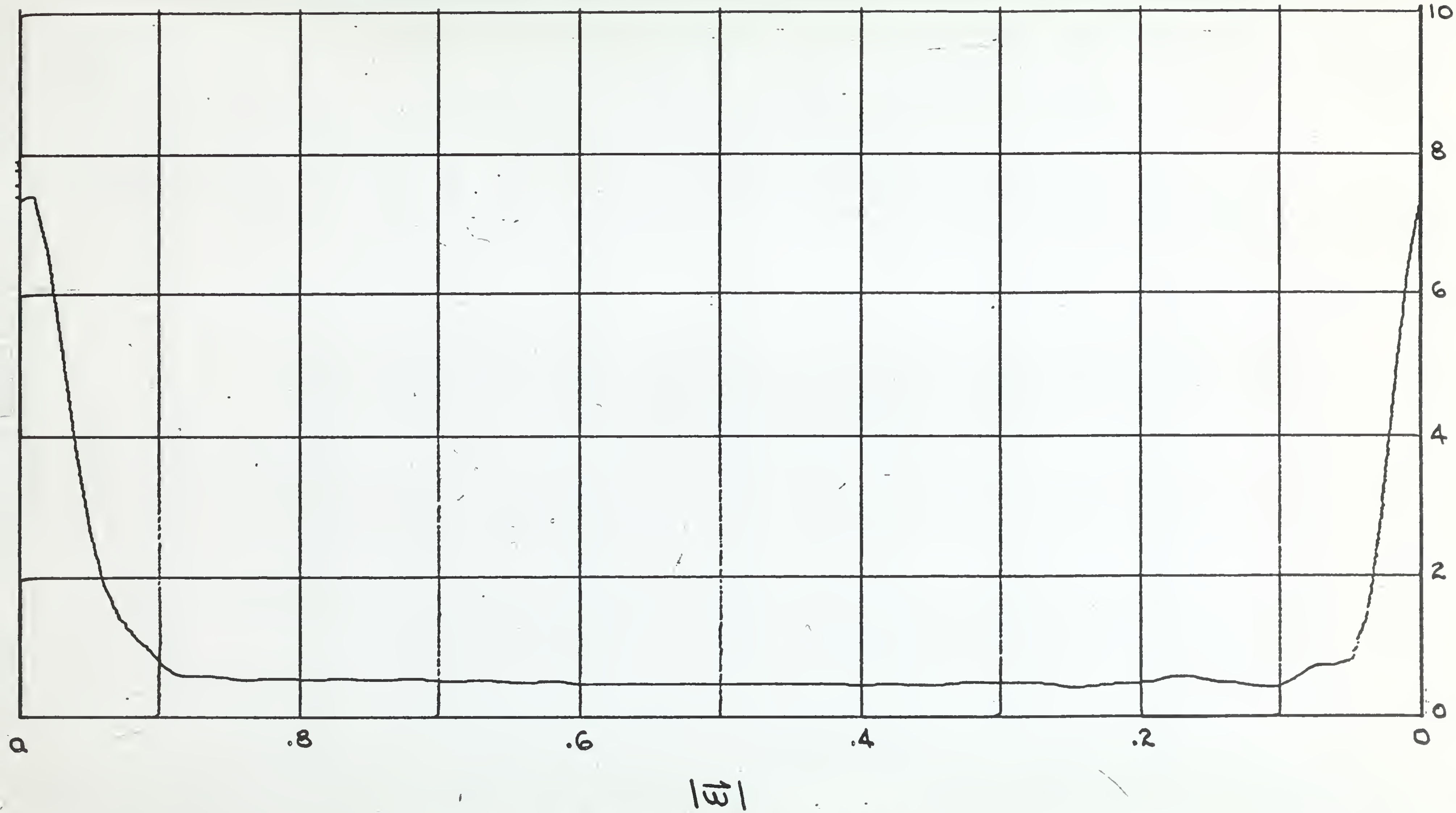

FIGURE 10. Patterson Function for specimen aged 14 days

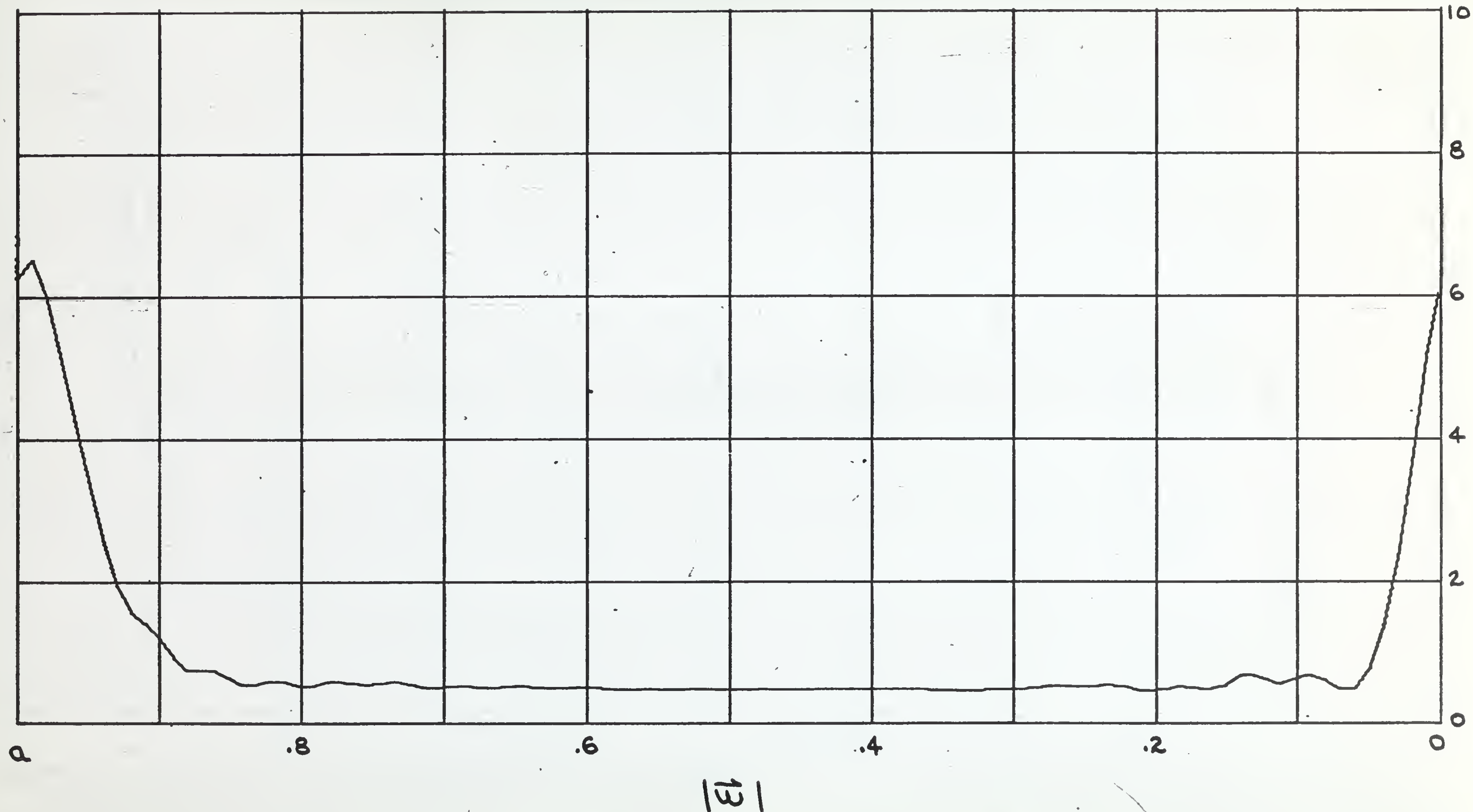

FIGURE 11. Patterson Function for specimen aged 30 days

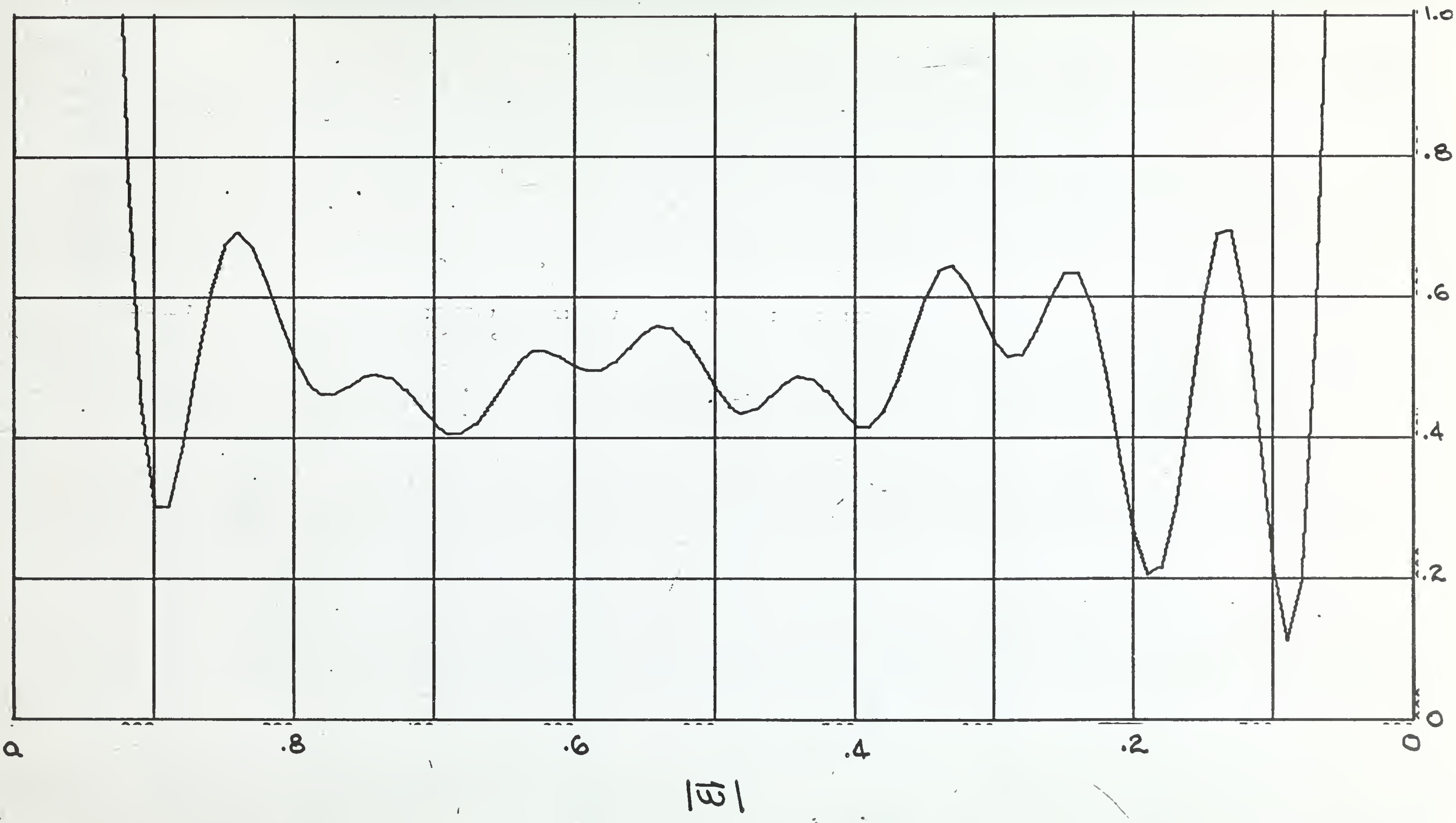

FIGURE 12. Patterson Function, as quenched specimen

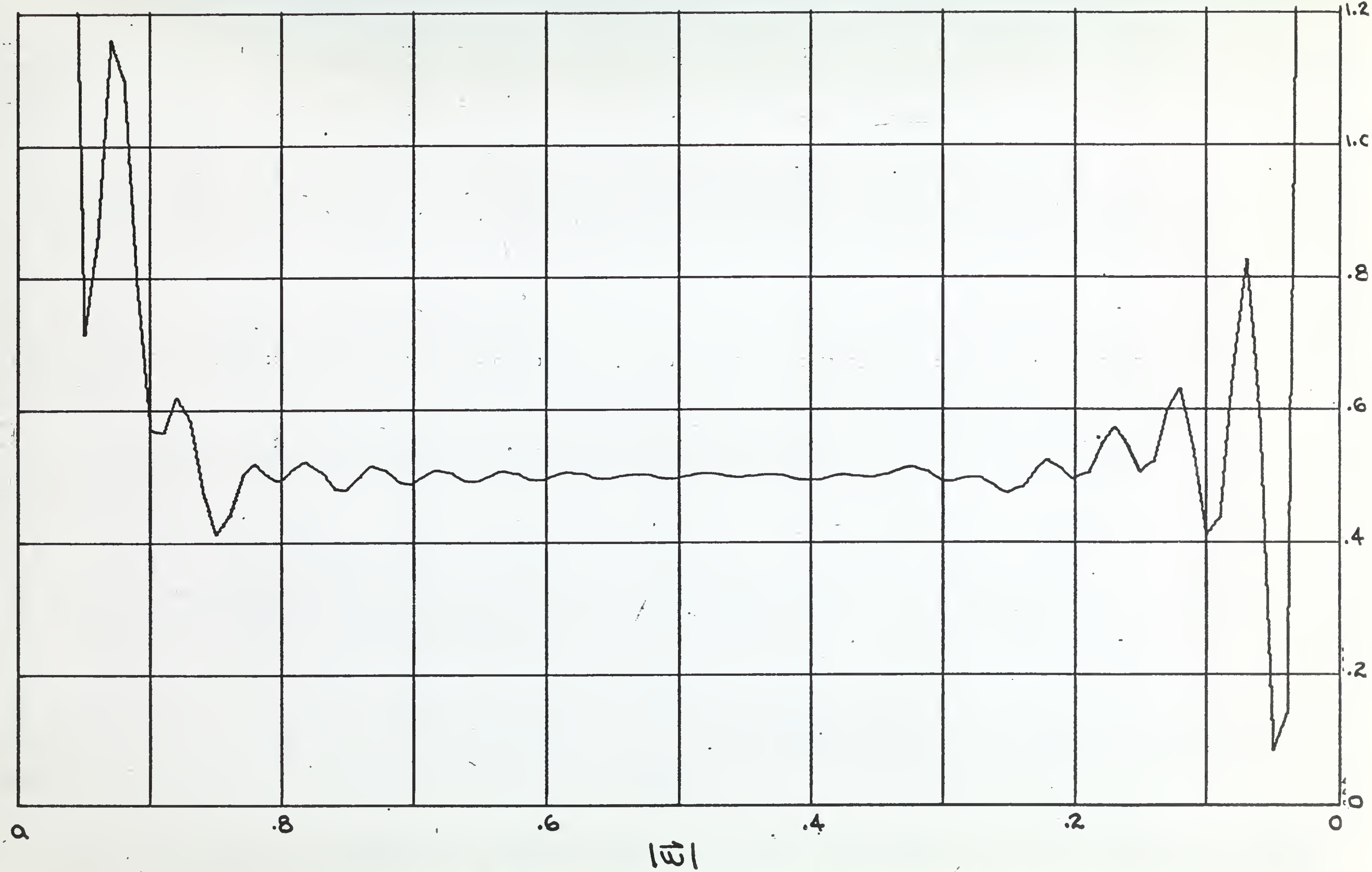

FIGURE 13. Patterson Function, aged 65 days at room temperature

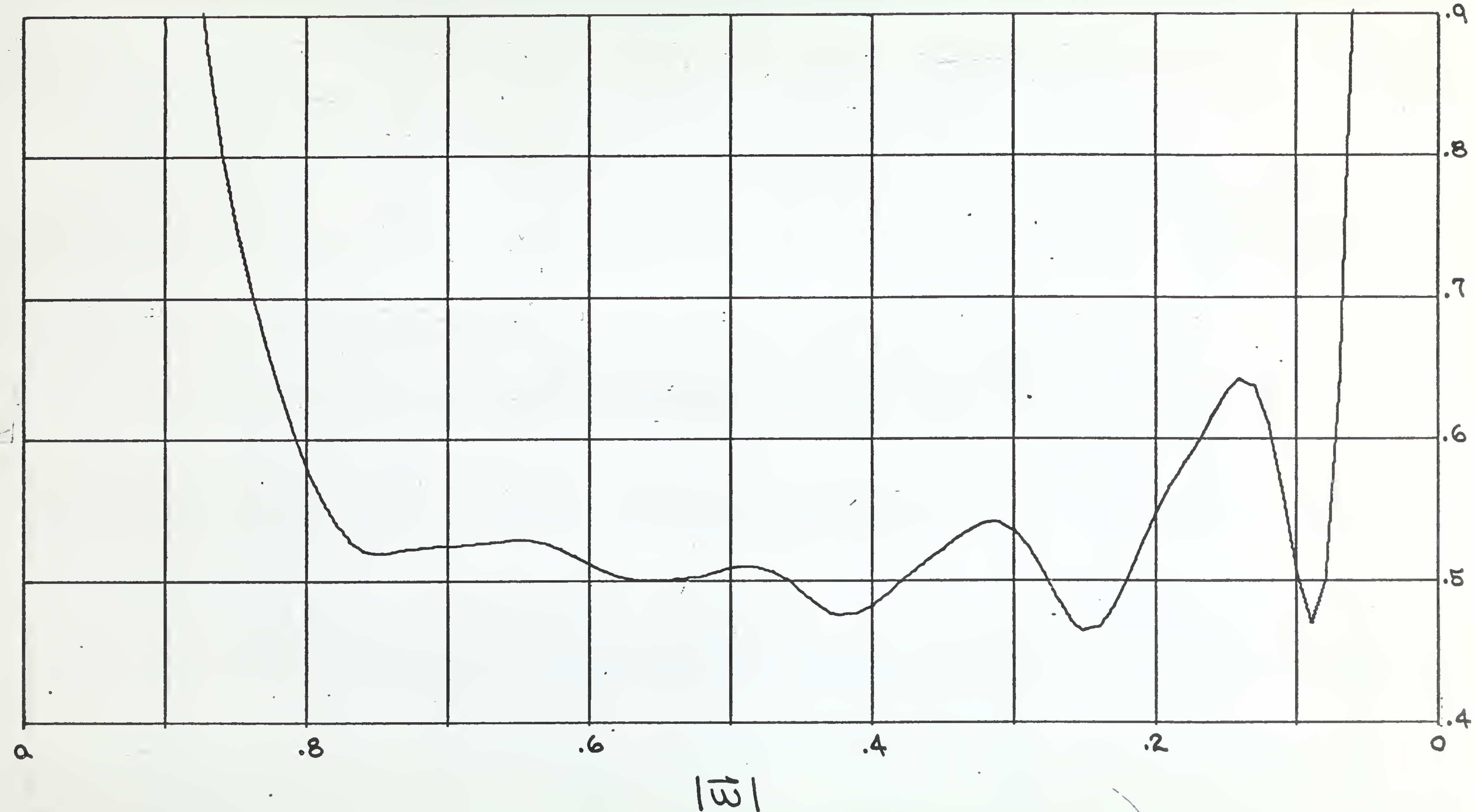

FIGURE 14. Patterson Function for specimen aged 1 day

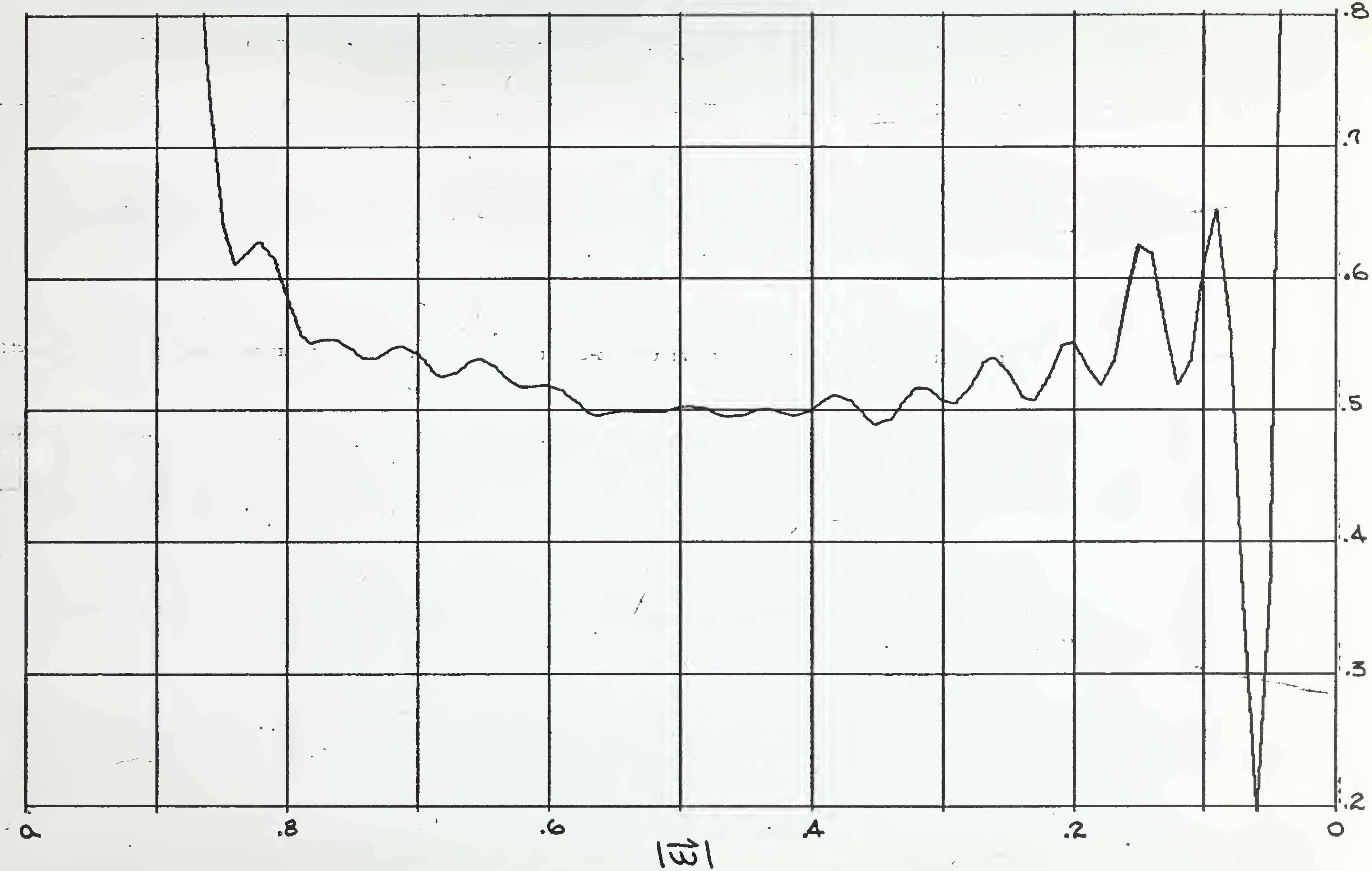

FIGURE 15. Patterson Function for specimen aged 2 days

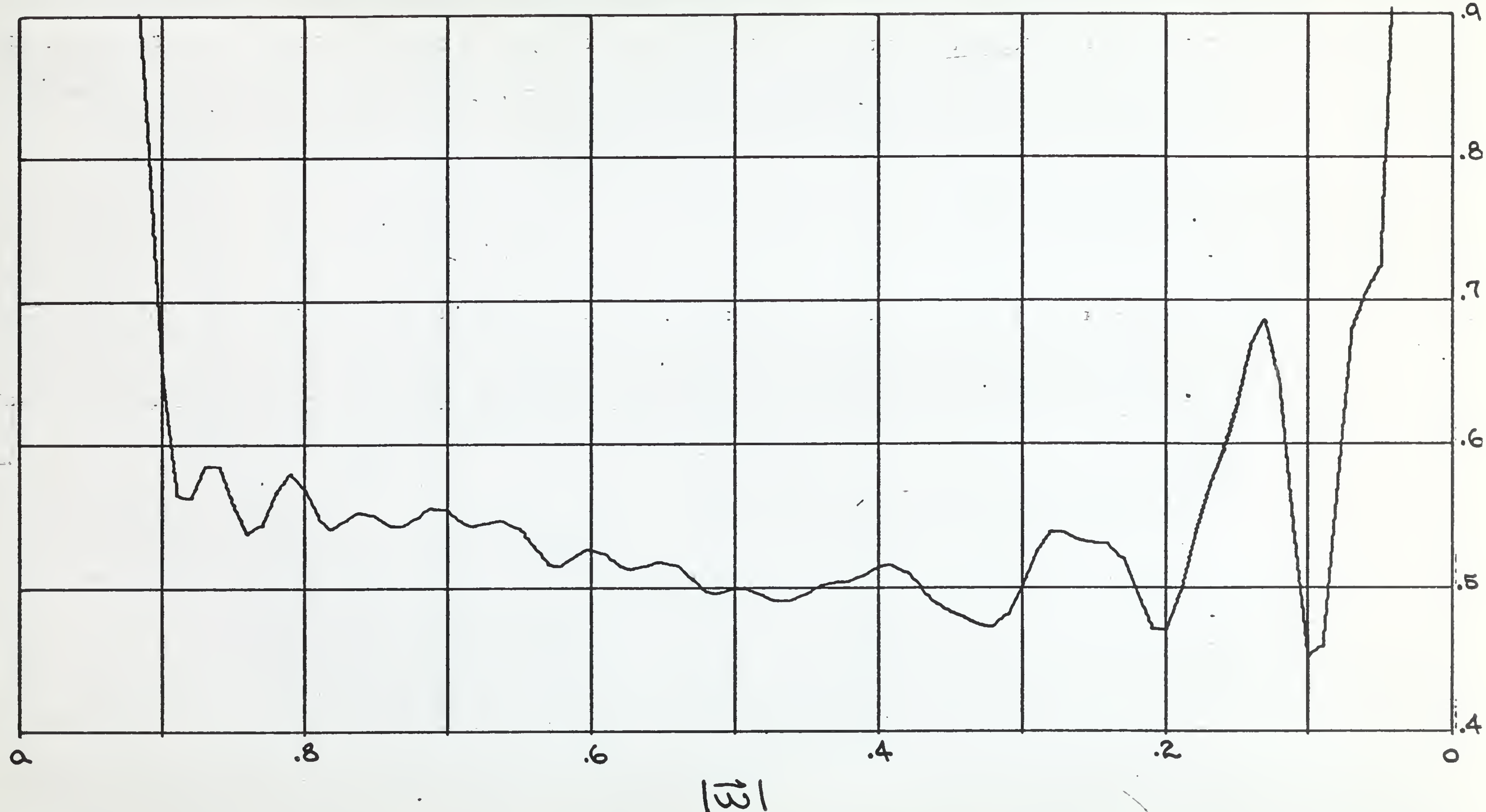

FIGURE 16. Patterson Function for specimen aged 5 days

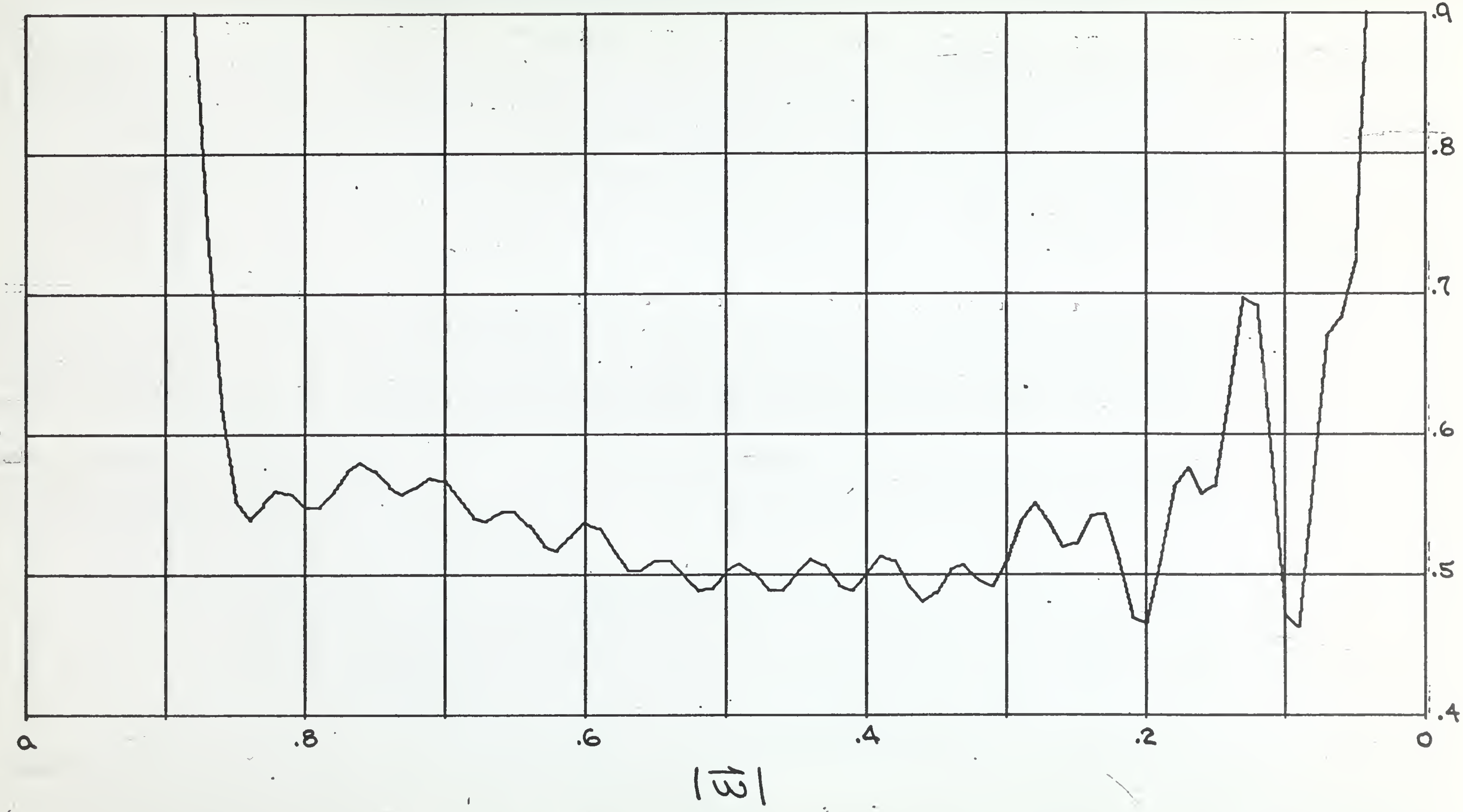

FIGURE 17. Patterson Function for specimen aged 9 days

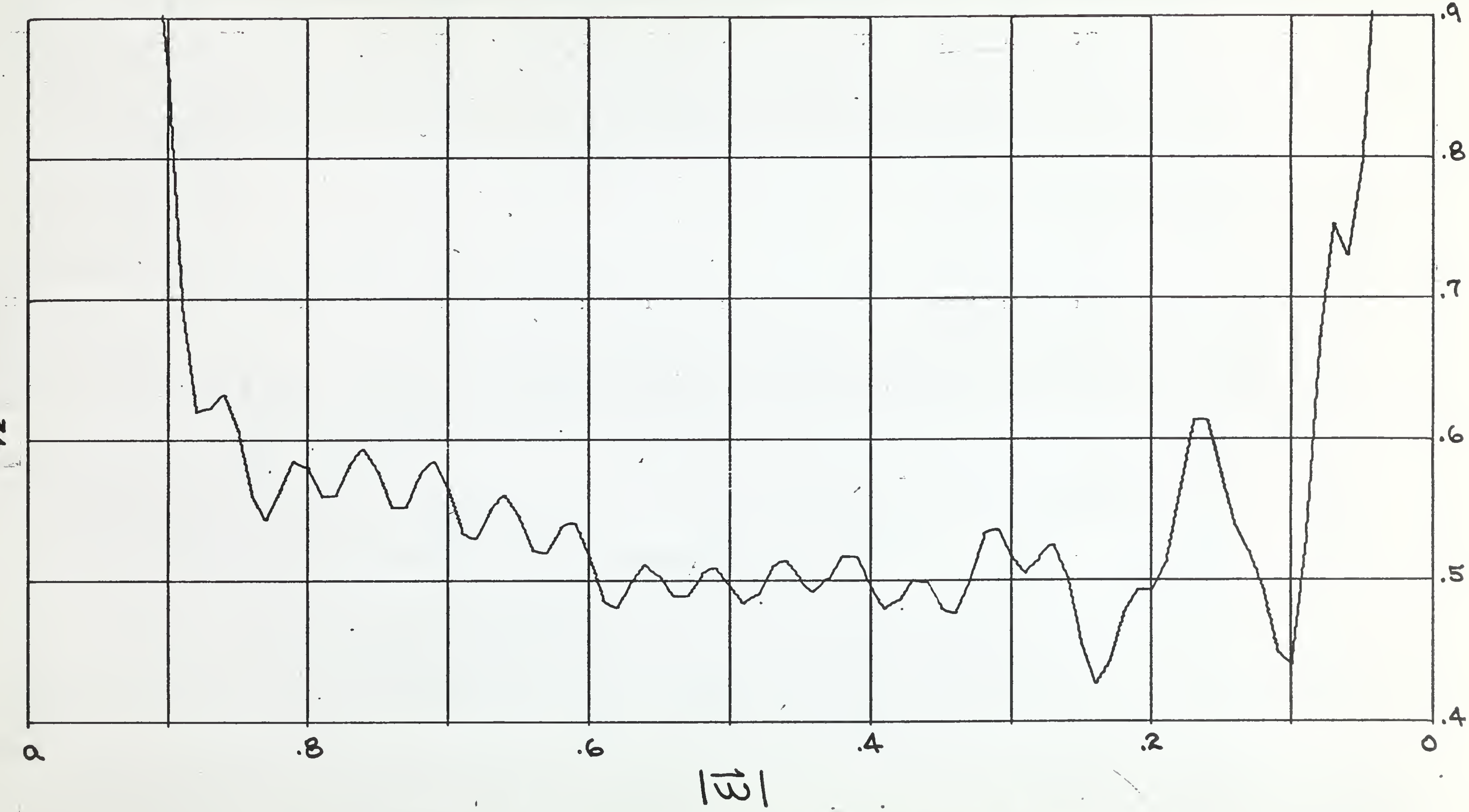

FIGURE 18. Patterson Function for specimen aged 14 days

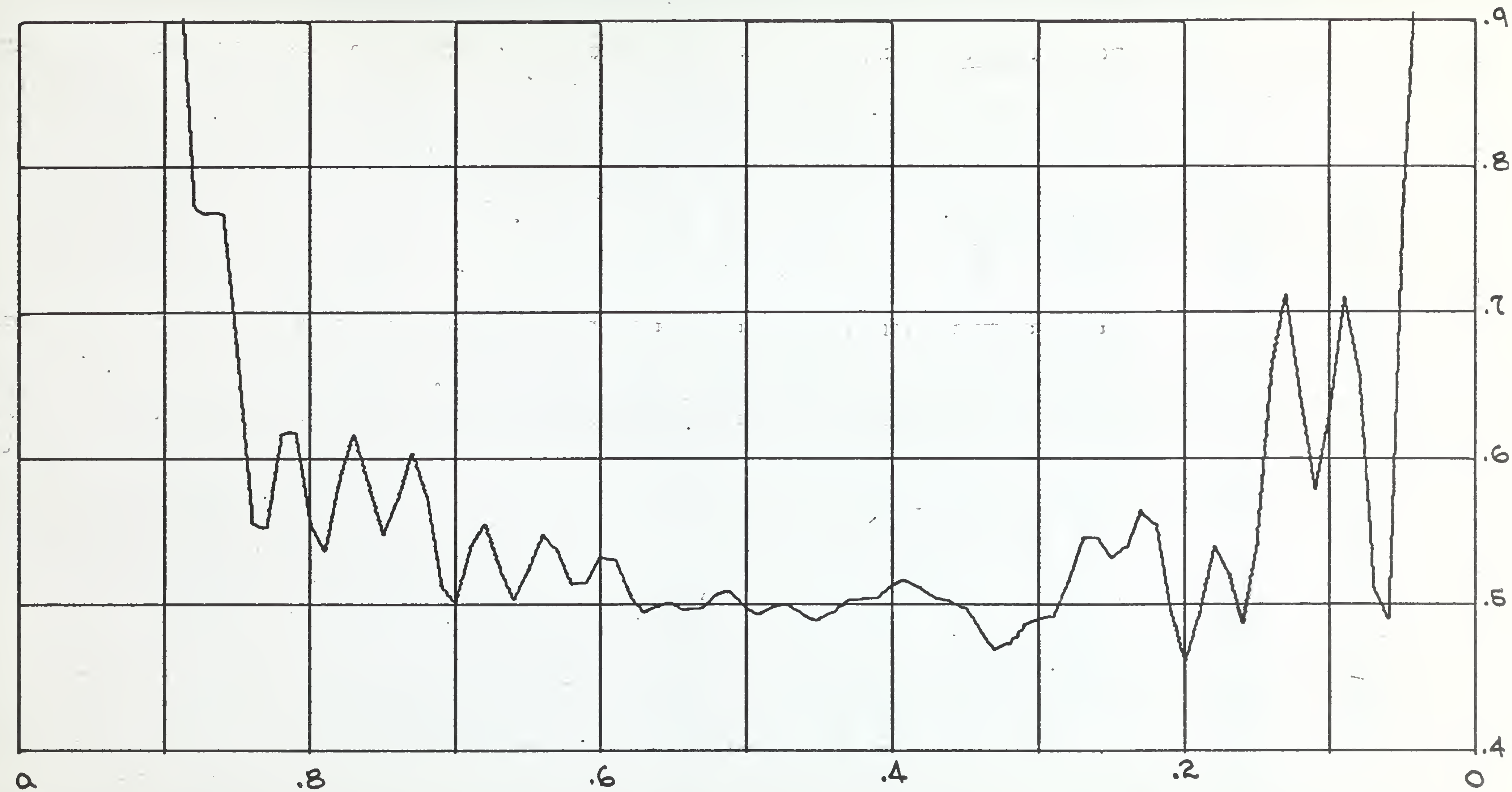

FIGURE 19. Patterson Function for specimen aged 30 days

APPENDIX II

FOURIER COEFFICIENTS FOR REFERENCE, BROADENED AND CORRECTED PROFILES

The column headings for the tabulated Fourier coefficients are as follows:

N, the harmonic number

ALPHA, coefficient of the real component

BETA, coefficient of the imaginary component

INTENSITY for each harmonic is computed by

$$I_N = \frac{L}{2}\left(A_N^2 + B_N^2\right)$$

where L is the number of equal intervals between the data points used to describe the curve.

The corrected coefficients are normalized. The arrow in the "corrected" column indicates the number of harmonics used in the synthesis of the Patterson function.

ALUMINUM - COPPER, AS QUENCHED, ALPHA(200)

N	REFERENCE ALPHA	REFERENCE BETA	REFERENCE INTENSITY	BROADENED ALPHA	BROADENED BETA	BROADENED INTENSITY	CORRECTED ALPHA	CORRECTED BETA	CORRECTED INTENSITY
0	424.5239	.0000	*	377.9841	.0000	*	1.0000	.0000	36.50000
1	-356.0011	-85.1635	*	-315.7390	-62.5321	*	.9868	-.0388	35.59956
2	218.7512	107.1233	*	191.0332	70.1629	*	.9334	-.0968	32.14162
3	-116.5124	-56.5779	*	-95.6457	-32.2461	*	.8682	-.1108	27.96028
4	79.5109	-18.0741	*	52.8696	-15.3019	*	.7568	-.0441	20.97800
5	-88.9668	64.5325	*	-44.2284	44.0159	*	.6300	-.0987	14.84041
6	110.3999	-67.9993	*	44.3316	-42.7636	*	.5212	-.1140	10.39029
7	-113.7543	44.1530	*	-36.9466	25.3555	*	.4015	-.0945	6.20902
8	95.7418	-16.9306	*	22.9504	-8.8440	*	.2789	-.0544	2.94636
9	-67.3357	1.5459	*	-9.1314	-.1727	3044.55541	.1522	.0064	.84657
10	39.2998	.0324	*	.7309	1.8143	139.64358	.0209	.0518	.11405
11	-20.4230	6.7041	*	1.8473	-1.2335	180.09652	-.1118	.0311	.49167
12	11.7353	-14.0901	*	-1.7849	1.2316	171.64316	-.1279	-.0357	.64391
13	-9.3183	17.6994	*	.9584	-1.1693	83.43677	-.0832	-.0170	.26305
14	9.3500	-17.5258	*	-.4958	1.0462	48.92149	-.0654	.0031	.15640
15	-8.8448	14.7399	*	.3329	-.9042	33.88971	-.0619	.0117	.14467
16	7.4495	-11.1888	6594.95398	-.2103	.7612	22.76525	-.0627	.0206	.15893
17	-5.7849	8.1215	3628.97263	.6779	-.5028	26.00083	-.0904	-.0293	.32988
18	4.0941	-5.4134	1681.43104	-1.1662	.1887	50.94018	-.1413	-.1351	1.39486
19	-2.4570	3.0678	563.86527	1.1371	.1584	48.10659	-.1678	-.2819	3.92807
20	.3876	-1.4035	77.38596	-.7300	-.6084	32.96068	.3025	-.6677	19.61029
21	1.6177	1.0510	135.83905	.2431	.6384	17.03124	.3211	.2346	5.77260
22	-2.5346	-1.7223	342.75231	.1267	-.3671	5.50576	.0372	.1374	.73958
23	2.4615	2.0579	375.72000	-.5904	.0594	12.85055	-.1452	.1485	1.57473
24	-1.8775	-1.9165	262.72223	.8686	.2941	30.69483	-.3424	.1736	5.37921
25	1.0426	1.7232	148.06382	-.6953	-.1965	19.05519	-.2945	.2750	5.92536
26	.0369	-1.2941	61.17480	.3999	-.4556	13.41486	.4050	.3355	10.09633
27	-1.0065	.2893	40.02807	-.4683	1.3297	72.53882	.8766	-1.2319	83.43645
28	1.0148	1.3059	99.83289	.9769	-1.8255	156.46142	-.5718	-1.2845	72.15785
29	-.0289	-2.4648	221.77489	-1.2316	1.4163	128.57776	-.6387	-.5687	26.69337
30	-1.0579	2.4708	263.67316	.9437	-.5095	41.97995	-.3509	-.2787	7.33037

ALUMINUM - COPPER, AGED 65 DAYS, ROOM TEMP.

	REFERENCE			BROADENED			CORRECTED		
N	ALPHA	BETA	INTENSITY	ALPHA	BETA	INTENSITY	ALPHA	BETA	INTENSITY
0	212.2636	.0000	*	320.0457	.0000	*	1.0000	.0000	72.50000
1	-202.8862	-23.7948	*	-303.2955	-23.0191	*	.9867	-.0405	70.70556
2	177.5764	42.7913	*	259.5999	39.7807	*	.9502	-.0804	65.92799
3	-143.4071	-53.2603	*	-203.7834	-46.9685	*	.8991	-.1167	59.59689
4	108.4696	53.4296	*	149.5422	44.4720	*	.8436	-.1436	53.09314
5	-78.8768	-43.9264	*	-104.2937	-33.8684	*	.7904	-.1554	47.04428
6	57.5536	27.5293	*	70.4234	17.6193	*	.7395	-.1507	41.28969
7	-44.8248	-8.2410	*	-48.1398	.7996	*	.6869	-.1381	35.58930
8	39.6414	-9.9494	*	36.2017	-17.4563	*	.6387	-.1317	30.83802
9	-40.3539	24.0817	*	-31.6977	29.4080	*	.5968	-.1272	26.99830
10	44.8642	-32.6689	*	30.9983	-35.5281	*	.5494	-.1252	23.01831
11	-50.7073	35.5883	*	-31.2676	36.1215	*	.4962	-.1242	18.96630
12	55.5099	-33.6947	*	30.9134	-32.3295	*	.4412	-.1184	15.13232
13	-57.6571	28.4092	*	-29.1141	25.9102	*	.3876	-.1070	11.72503
14	56.6511	-21.3702	*	25.5672	-18.8386	*	.3349	-.0942	8.77359
15	-52.8971	14.1218	*	-20.6089	12.5489	*	.2804	-.0825	6.19405
16	47.1718	-7.8516	*	15.0723	-7.5947	*	.2235	-.0696	3.97242
17	-40.2287	3.2504	*	-9.8276	4.0383	8184.53462	.1663	-.0531	2.21016
18	32.7375	-.5394	*	5.4741	-1.8355	2416.78718	.1115	-.0353	.99164
19	-25.3779	-.3958	*	-2.3135	.7364	427.34724	.0601	-.0202	.29180
20	18.8201	-.1260	*	.3742	-.2071	13.26250	.0132	-.0072	.01647
21	-13.5507	1.6542	*	.5647	-.2242	26.76409	-.0286	.0075	.06317
22	9.7239	-3.6652	7829.10211	-.8563	.6535	84.12274	-.0658	.0198	.34266
23	-7.1924	5.6586	6071.88140	.8341	-.9701	118.67171	-.0910	.0179	.62329
24	5.6763	-7.2762	6174.31331	-.7389	1.1731	139.34205	-.0991	.0100	.71971
25	-4.9044	8.3603	6811.24466	.6966	-1.3618	169.61878	-.1045	.0060	.79417
26	4.6383	-8.9116	7317.45548	-.7170	1.5490	211.22686	-.1126	.0052	.92056
27	-4.6388	8.9936	7424.20080	.7541	-1.6601	241.02856	-.1194	.0059	1.03534
28	4.6763	-8.6738	7039.96705	-.7902	1.6534	243.45932	-.1232	.0060	1.10286
29	-4.5967	8.0321	6209.17603	.8365	-1.5186	217.92803	-.1242	.0020	1.11929
30	4.3638	-7.1866	5124.97061	-.8836	1.2113	162.98581	-.1179	-.0100	1.01420

ALUMINUM - COPPER, AGED 1 DAY, ALPHA(200)

N	REFERENCE ALPHA	REFERENCE BETA	REFERENCE INTENSITY	BROADENED ALPHA	BROADENED BETA	BROADENED INTENSITY	CORRECTED ALPHA	CORRECTED BETA	CORRECTED INTENSITY
0	272.9092	.0000	*	633.5042	.0000	*	1.0000	.0000	28.50000
1	-253.3929	-38.3807	*	-556.2890	5.4915	*	.9232	-.1492	24.92215
2	204.1382	64.2012	*	400.4425	-.0140	*	.7690	-.2419	18.52048
3	-145.9263	-69.5118	*	-252.6605	-.2795	*	.6083	-.2889	12.92344
4	97.1253	54.0857	*	136.9401	-6.2747	*	.4518	-.2794	8.04240
5	-65.9009	-25.2199	*	-66.0147	18.1046	*	.3369	-.2473	4.97759
6	52.0676	-6.1652	*	28.6231	-26.5200	*	.2592	-.1887	2.92944
7	-51.8159	30.6997	*	-11.2499	26.0159	*	.1641	-.1191	1.17143
8	59.6443	-43.6824	*	5.5405	-20.3287	*	.0960	-.0765	.42962
9	-68.9126	45.0810	*	-4.2348	11.8307	4500.13115	.0524	-.0397	.12316
10	73.9499	-37.8842	*	3.4670	-4.8932	1024.97191	.0276	-.0144	.02755
11	-72.4441	26.3834	*	-1.7481	.7104	101.47115	.0105	-.0004	.00317
12	65.3251	-14.7309	*	-.5421	.1465	8.98568	-.0036	.0002	.00037
13	-54.6831	5.8030	*	2.0573	.0106	120.63425	-.0160	-.0018	.00740
14	42.4343	-.7761	*	-2.0831	.3735	127.64867	-.0212	.0034	.01315
15	-30.4131	-.4971	*	1.6064	-.9232	97.83133	-.0225	.0134	.01962
16	20.3702	-1.0859	*	-1.2799	1.3035	95.11034	-.0285	.0260	.04242
17	-13.2810	4.2160	*	1.2681	-1.0181	75.37133	-.0469	.0181	.07204
18	9.0062	-7.5043	7764.56071	-.7880	.0862	17.91007	-.0243	-.0161	.02419
19	-6.8247	9.9695	8247.17289	.5258	1.2750	54.21286	.0269	-.0412	.06893
20	6.0248	-11.2912	9254.05512	-.4827	-2.2009	144.69246	.0577	-.0492	.16395
21	-5.9605	11.5713	9572.36217	.4903	2.3768	167.85157	.0625	-.0504	.18386
22	6.0063	-10.9942	8867.57990	-.6102	-2.2178	150.78947	.0569	-.0550	.17830
23	-5.7784	9.7902	7301.99903	1.0705	2.0642	154.09574	.0467	-.0747	.22128
24	5.2708	-8.3076	5469.12634	-1.7418	-1.7080	169.60731	.0223	-.1045	.32517
25	-4.6351	6.8728	3882.60657	1.8352	1.3217	145.77603	.0036	-.1175	.39368
26	3.9443	-5.5973	2649.16786	-1.5581	-.5650	78.28816	-.0274	-.1006	.30986
27	-3.2275	4.4295	1697.11506	1.0780	-.5379	41.36634	-.0841	-.0436	.25558
28	2.5407	-3.3352	993.20358	-.4140	1.6264	80.27302	-.1587	.0674	.84746
29	-1.8742	2.3417	508.27807	-.4140	-1.6264	80.27302	-.1452	.1924	1.65598
30	1.1128	-1.4940	196.07848	1.0780	.5379	41.36634	.0492	.2742	2.21209

ALUMINUM - COPPER, AGED 2 DAYS, (200)

N	REFERENCE ALPHA	REFERENCE BETA	REFERENCE INTENSITY	BROADENED ALPHA	BROADENED BETA	BROADENED INTENSITY	CORRECTED ALPHA	CORRECTED BETA	CORRECTED INTENSITY
0	212.2636	.0000	*	344.4746	.0000	*	1.0000	.0000	36.50000
1	-202.8862	-23.7948	*	-310.9229	19.4131	*	.9247	-.1674	32.23195
2	177.5764	42.7913	*	245.0116	-24.3435	*	.7843	-.2735	25.18166
3	-143.4071	-53.2603	*	-180.8538	22.5434	*	.6513	-.3387	19.67086
4	108.4696	53.4296	*	121.3857	-17.0968	*	.5164	-.3515	14.24417
5	-78.8768	-43.9264	*	-74.5381	12.1202	*	.4042	-.3198	9.69626
6	57.5536	27.5293	*	41.5659	-11.1965	*	.3155	-.2708	6.30958
7	-44.8248	-8.2410	*	-20.6456	11.7631	*	.2458	-.2069	3.76710
8	39.6414	-9.9494	*	10.0908	-12.3421	9276.53257	.1929	-.1434	2.10860
9	-40.3539	24.0817	*	-6.1504	11.7078	6383.84225	.1479	-.0905	1.09761
10	44.8642	-32.6689	*	6.0773	-9.7776	4837.50148	.1185	-.0480	.59635
11	-50.7073	35.5883	*	-6.7113	6.4467	3160.93420	.0915	-.0141	.31273
12	55.5099	-33.6947	*	6.8822	-2.6636	1987.75758	.0689	.0123	.17899
13	-57.6571	28.4092	*	-6.4844	-.8414	1560.57395	.0522	.0347	.14342
14	56.6511	-21.3702	*	5.3601	2.9456	1365.37542	.0405	.0473	.14141
15	-52.8971	14.1218	*	-3.6652	-3.2905	885.52473	.0303	.0464	.11217
16	47.1718	-7.8516	*	1.9539	2.8048	426.48093	.0189	.0398	.07081
17	-40.2287	3.2504	*	-.5354	-1.3138	73.46254	.0065	.0207	.01712
18	32.7375	-.5394	*	-.1272	.0798	.82297	-.0024	.0015	.00029
19	-25.3779	-.3958	*	.3888	.6638	21.60106	-.0097	-.0160	.01273
20	18.8201	-.1260	*	-.6704	-1.1941	68.44911	-.0217	-.0392	.07337
21	-13.5507	1.6542	*	.8325	.9234	56.41803	-.0322	-.0459	.11495
22	9.7239	-3.6652	7829.10211	-1.0393	-.2046	40.95066	-.0534	-.0331	.14399
23	-7.1924	5.6586	6071.88140	.9628	-.4139	40.08705	-.0682	-.0182	.18174
24	5.6763	-7.2762	6174.31331	-.9739	.4753	42.86530	-.0650	-.0318	.19111
25	-4.9044	8.3603	6811.24466	1.0220	.1024	38.50799	-.0273	-.0593	.15563
26	4.6383	-8.9116	7317.45548	-.9250	-.7133	49.80230	-.0126	-.0705	.18735
27	-4.6388	8.9936	7424.20080	.8047	1.3969	94.85720	.0531	-.0825	.35172
28	4.6763	-8.6738	7039.96705	-.7443	-2.1382	187.09480	.0956	-.1044	.73159
29	-4.5967	8.0321	6209.17603	.5055	2.0800	167.24193	.1035	-.0980	.74146
30	4.3638	-7.1866	5124.97061	-.0843	-1.8956	131.41927	.1155	-.0774	.70590

ALUMINUM - COPPER, AGED 5 DAYS, (200)

N	REFERENCE ALPHA	REFERENCE BETA	REFERENCE INTENSITY	BROADENED ALPHA	BROADENED BETA	BROADENED INTENSITY	CORRECTED ALPHA	CORRECTED BETA	CORRECTED INTENSITY
0	212.2636	.0000	*	380.2606	.0000	*	1.0000	.0000	36.50000
1	-202.8862	-23.7948	*	-347.5288	-6.4187	*	.9452	-.0932	32.92859
2	177.5764	42.7913	*	286.1070	21.0600	*	.8651	-.1423	28.05436
3	-143.4071	-53.2603	*	-223.4243	-22.7071	*	.7931	-.2062	24.51022
4	108.4696	53.4296	*	161.4440	18.0164	*	.7054	-.2547	20.52775
5	-78.8768	-43.9264	*	-108.8494	-9.4644	*	.6164	-.2763	16.65670
6	57.5536	27.5293	*	68.0840	-3.0401	*	.5259	-.2810	12.97811
7	-44.8248	-8.2410	*	-40.0333	14.8376	*	.4494	-.2674	9.98049
8	39.6414	-9.9494	*	21.6672	-22.4212	*	.3616	-.2250	6.61911
9	-40.3539	24.0817	*	-11.4631	26.3574	*	.2774	-.1991	4.25453
10	44.8642	-32.6689	*	6.6892	-27.4251	*	.2168	-.1834	2.94250
11	-50.7073	35.5883	*	-5.4358	25.5109	*	.1721	-.1600	2.01622
12	55.5099	-33.6947	*	5.4410	-21.8855	*	.1376	-.1366	1.37174
13	-57.6571	28.4092	*	-5.8108	17.0901	*	.1109	-.1108	.89698
14	56.6511	-21.3702	*	5.7843	-12.0156	6490.84669	.0890	-.0848	.55169
15	-52.8971	14.1218	*	-4.9626	7.7403	3085.67741	.0692	-.0632	.32076
16	47.1718	-7.8516	*	3.4774	-4.5245	1188.53833	.0487	-.0454	.16195
17	-40.2287	3.2504	*	-2.1525	2.1434	336.80525	.0321	-.0272	.06443
18	32.7375	-.5394	*	.8356	-.7900	48.26578	.0145	-.0132	.01403
19	-25.3779	-.3958	*	.0431	-.0156	.07655	-.0009	.0004	.00004
20	18.8201	-.1260	*	-.2092	.2880	4.62610	-.0063	.0085	.00407
21	-13.5507	1.6542	*	-.0354	-.1328	.68936	.0008	.0056	.00115
22	9.7239	-3.6652	7829.10211	.4130	-.1467	7.01191	.0235	.0005	.02023
23	-7.1924	5.6586	6071.88140	-.9178	.1311	31.37090	.0489	.0283	.11672
24	5.6763	-7.2762	6174.31331	1.1286	.0807	46.73058	.0381	.0568	.17098
25	-4.9044	8.3603	6811.24466	-1.1946	-.3028	55.43283	.0198	.0682	.18385
26	4.6383	-8.9116	7317.45548	.9716	.1250	35.02601	.0188	.0511	.10813
27	-4.6388	8.9936	7424.20080	-.4013	-.0093	5.88221	.0097	.0199	.01790
28	4.6763	-8.6738	7039.96705	-.0620	-.0031	.14065	-.0015	-.0032	.00045
29	-4.5967	8.0321	6209.17603	.1917	-.0672	1.50601	-.0093	-.0080	.00548
30	4.3638	-7.1866	5124.97061	-.3360	.1281	4.71975	-.0188	-.0147	.02080

ALUMINUM - COPPER, AGED 9 DAYS (200)

N	REFERENCE ALPHA	REFERENCE BETA	REFERENCE INTENSITY	BROADENED ALPHA	BROADENED BETA	BROADENED INTENSITY	CORRECTED ALPHA	CORRECTED BETA	CORRECTED INTENSITY
0	212.2636	.0000	*	424.2419	.0000	*	1.0000	.0000	36.50000
1	-202.8862	-23.7948	*	-382.4330	3.9066	*	.9292	-.1186	32.02837
2	177.5764	42.7913	*	305.1963	6.5432	*	.8169	-.1784	25.52057
3	-143.4071	-53.2603	*	-230.9527	-10.3074	*	.7198	-.2314	20.86745
4	108.4696	53.4296	*	158.5492	10.0812	*	.6070	-.2525	15.77388
5	-78.8768	-43.9264	*	-100.6373	-6.9083	*	.5059	-.2379	11.40673
6	57.5536	27.5293	*	61.0015	-.2606	*	.4307	-.2083	8.35374
7	-44.8248	-8.2410	*	-37.1149	8.6211	*	.3836	-.1668	6.38650
8	39.6414	-9.9494	*	23.6549	-17.0099	*	.3316	-.1315	4.64345
9	-40.3539	24.0817	*	-16.8061	22.4535	*	.2762	-.1136	3.25463
10	44.8642	-32.6689	*	13.2627	-24.6871	*	.2277	-.1095	2.32982
11	-50.7073	35.5883	*	-11.1317	23.2172	*	.1813	-.1018	1.57842
12	55.5099	-33.6947	*	9.7005	-19.5388	*	.1420	-.0899	1.03117
13	-57.6571	28.4092	*	-8.3101	14.6153	*	.1083	-.0735	.62515
14	56.6511	-21.3702	*	7.0705	-9.5066	5123.46361	.0824	-.0529	.34986
15	-52.8971	14.1218	*	-5.9427	5.5071	2395.99743	.0655	-.0346	.20010
16	47.1718	-7.8516	*	4.8500	-2.4835	1083.69172	.0543	-.0173	.11863
17	-40.2287	3.2504	*	-3.5517	.6164	474.29457	.0445	-.0041	.07289
18	32.7375	-.5394	*	1.8694	.1824	128.77089	.0285	.0033	.03007
19	-25.3779	-.3958	*	-.2066	-.6544	17.19042	.0043	.0128	.00668
20	18.8201	-.1260	*	-1.1289	.3098	50.01608	-.0301	.0080	.03535
21	-13.5507	1.6542	*	1.5730	-.2392	92.39587	-.0583	.0017	.12412
22	9.7239	-3.6652	7829.10211	-1.4903	.4465	88.34625	-.0747	-.0052	.20480
23	-7.1924	5.6586	6071.88140	1.5197	-.5672	96.04438	-.0845	-.0270	.28708
24	5.6763	-7.2762	6174.31331	-1.0860	.7890	65.77347	-.0699	-.0201	.19334
25	-4.9044	8.3603	6811.24466	1.1753	-.9592	84.00012	-.0734	-.0273	.22383
26	4.6383	-8.9116	7317.45548	-1.2288	.8935	84.25962	-.0677	-.0337	.20899
27	-4.6388	8.9936	7424.20080	.9639	-.8302	59.06687	-.0583	-.0235	.14440
28	4.6763	-8.6738	7039.96705	-.5550	1.0841	54.14024	-.0618	.0013	.13958
29	-4.5967	8.0321	6209.17603	.0194	-1.2544	57.44297	-.0594	.0328	.16791
30	4.3638	-7.1866	5124.97061	.5901	1.2906	73.50305	-.0474	.0699	.26030

ALUMINUM - COPPER, AGED 13.8 DAYS, (200)

N	REFERENCE ALPHA	REFERENCE BETA	REFERENCE INTENSITY	BROADENED ALPHA	BROADENED BETA	BROADENED INTENSITY	CORRECTED ALPHA	CORRECTED BETA	CORRECTED INTENSITY
0	212.2636	.0000	*	316.6900	.0000	*	1.0000	.0000	72.50000
1	-202.8862	-23.7948	*	-289.9945	-2.1803	*	.9459	-.1037	65.64270
2	177.5764	42.7913	*	236.1304	17.1583	*	.8571	-.1418	54.71758
3	-143.4071	-53.2603	*	-180.9840	-24.6191	*	.7809	-.1750	46.43077
4	108.4696	53.4296	*	126.7580	20.7475	*	.6811	-.2073	36.75314
5	-78.8768	-43.9264	*	-82.4277	-13.7706	*	.5844	-.2084	27.90655
6	57.5536	27.5293	*	50.9876	4.0988	*	.5018	-.1923	20.93739
7	-44.8248	-8.2410	*	-29.7785	5.1430	*	.4170	-.1536	14.31913
8	39.6414	-9.9494	*	17.6923	-12.6012	*	.3317	-.1298	9.19938
9	-40.3539	24.0817	*	-11.7662	17.1354	*	.2694	-.1239	6.37232
10	44.8642	-32.6689	*	10.2284	-18.1034	*	.2286	-.1040	4.57193
11	-50.7073	35.5883	*	-10.1302	16.6098	*	.1929	-.0841	3.21228
12	55.5099	-33.6947	*	9.8996	-13.0331	*	.1572	-.0620	2.06902
13	-57.6571	28.4092	*	-9.1858	9.1886	*	.1283	-.0436	1.33081
14	56.6511	-21.3702	*	7.3433	-5.6544	6227.42863	.0981	-.0299	.76312
15	-52.8971	14.1218	*	-5.2110	2.7422	2513.91808	.0703	-.0160	.37676
16	47.1718	-7.8516	*	3.0788	-.9445	751.88555	.0447	-.0060	.14771
17	-40.2287	3.2504	*	-1.5577	-.0543	176.12715	.0257	.0030	.04857
18	32.7375	-.5394	*	.7154	.2912	43.25245	.0145	.0062	.01813
19	-25.3779	-.3958	*	-.2030	-.5355	23.77860	.0056	.0141	.01658
20	18.8201	-.1260	*	.0521	.7075	36.48248	.0017	.0252	.04627
21	-13.5507	1.6542	*	.3099	-.6330	36.01388	-.0189	.0290	.08682
22	9.7239	-3.6652	7829.10211	-.6355	.4786	45.88133	-.0492	.0144	.19087
23	-7.1924	5.6586	6071.88140	.8858	-.0818	57.36910	-.0547	-.0354	.30773
24	5.6763	-7.2762	6174.31331	-1.0173	-.1442	76.53635	-.0372	-.0647	.40374
25	-4.9044	8.3603	6811.24466	.8638	.3999	65.68729	-.0064	-.0655	.31411
26	4.6383	-8.9116	7317.45548	-.8275	-.6145	77.02411	.0109	-.0679	.34284
27	-4.6388	8.9936	7424.20080	.6962	.5986	61.12136	.0141	-.0592	.26814
28	4.6763	-8.6738	7039.96705	-.6213	-.5556	50.36376	.0132	-.0551	.23301
29	-4.5967	8.0321	6209.17603	.6748	.2239	36.64692	-.0102	-.0505	.19223
30	4.3638	-7.1866	5124.97061	-.6244	.1813	30.64891	-.0382	-.0350	.19478

ALUMINUM - COPPER, AGED 30 DAYS, (200)

	REFERENCE			BROADENED			CORRECTED		
N	ALPHA	BETA	INTENSITY	ALPHA	BETA	INTENSITY	ALPHA	BETA	INTENSITY
0	212.2636	.0000	*	369.4429	.0000	*	1.0000	.0000	36.50000
1	-202.8862	-23.7948	*	-334.1492	7.6581	*	.9309	-.1309	32.25673
2	177.5764	42.7913	*	263.6370	-1.5024	*	.8051	-.1989	25.10105
3	-143.4071	-53.2603	*	-194.6360	-2.2587	*	.6882	-.2466	19.50726
4	108.4696	53.4296	*	132.4841	2.6762	*	.5703	-.2668	14.47089
5	-78.8768	-43.9264	*	-83.0131	-.6498	*	.4636	-.2534	10.18717
6	57.5536	27.5293	*	47.6853	-5.0882	*	.3676	-.2266	6.80784
7	-44.8248	-8.2410	*	-27.0247	10.3078	*	.3116	-.1894	4.85273
8	39.6414	-9.9494	*	16.1152	-14.4511	*	.2692	-.1419	3.37958
9	-40.3539	24.0817	*	-10.1834	15.8331	*	.2061	-.1024	1.93357
10	44.8642	-32.6689	*	8.2661	-14.8716	*	.1598	-.0741	1.13247
11	-50.7073	35.5883	*	-7.6337	12.2128	7571.06916	.1230	-.0520	.65123
12	55.5099	-33.6947	*	7.0437	-8.9504	4734.92832	.0944	-.0354	.37068
13	-57.6571	28.4092	*	-5.8643	5.7135	2446.73558	.0696	-.0226	.19550
14	56.6511	-21.3702	*	4.7586	-2.7059	1093.78547	.0513	-.0081	.09849
15	-52.8971	14.1218	*	-3.3629	1.1023	457.13466	.0371	-.0021	.05034
16	47.1718	-7.8516	*	1.8809	-.1629	130.09620	.0226	.0018	.01878
17	-40.2287	3.2504	*	-.9626	-.3392	38.01910	.0133	.0059	.00770
18	32.7375	-.5394	*	.3708	.4919	13.84913	.0064	.0087	.00426
19	-25.3779	-.3958	*	-.2565	-.1933	3.76620	.0059	.0043	.00193
20	18.8201	-.1260	*	.2569	-.1092	2.84412	.0079	-.0033	.00265
21	-13.5507	1.6542	*	-.4875	.2319	10.63646	.0215	-.0072	.01884
22	9.7239	-3.6652	7829.10211	.4960	-.4876	17.65696	.0352	-.0156	.05398
23	-7.1924	5.6586	6071.88140	-.0743	.3995	6.02695	.0192	-.0168	.02376
24	5.6763	-7.2762	6174.31331	-.6681	-.1278	16.88960	-.0193	-.0377	.06547
25	-4.9044	8.3603	6811.24466	1.3470	-.1620	67.18876	-.0487	-.0640	.23608
26	4.6383	-8.9116	7317.45548	-1.4787	.1710	80.87907	-.0477	-.0705	.26453
27	-4.6388	8.9936	7424.20080	1.2383	.0625	56.10834	-.0291	-.0641	.18087
28	4.6763	-8.6738	7039.96705	-.6038	-.4874	21.97840	.0083	-.0445	.07472
29	-4.5967	8.0321	6209.17603	-.0728	.9586	33.73078	.0539	-.0256	.13001
30	4.3638	-7.1866	5124.97061	.5484	-1.1812	61.90438	.0884	-.0099	.28908

APPENDIX III

EXPERIMENTAL DIFFRACTION LINE PROFILES

The following instrumental settings were used in obtaining all of the diffraction line profiles. The abcissa is in degrees 2θ.

Cu $K\alpha$ radiation, 50 KV, 40 ma, Ni filter

Scan Speed $\frac{1}{8}^{\circ}$/minute, Chart Speed 30"/hour

Time Constant 2 seconds, Scale 64 x .6

Angular Aperture 1°, Receiving Slit 0.003"

Xenon Proportional Counter, 1725 volts

Base 7 volts, Window 3 volts

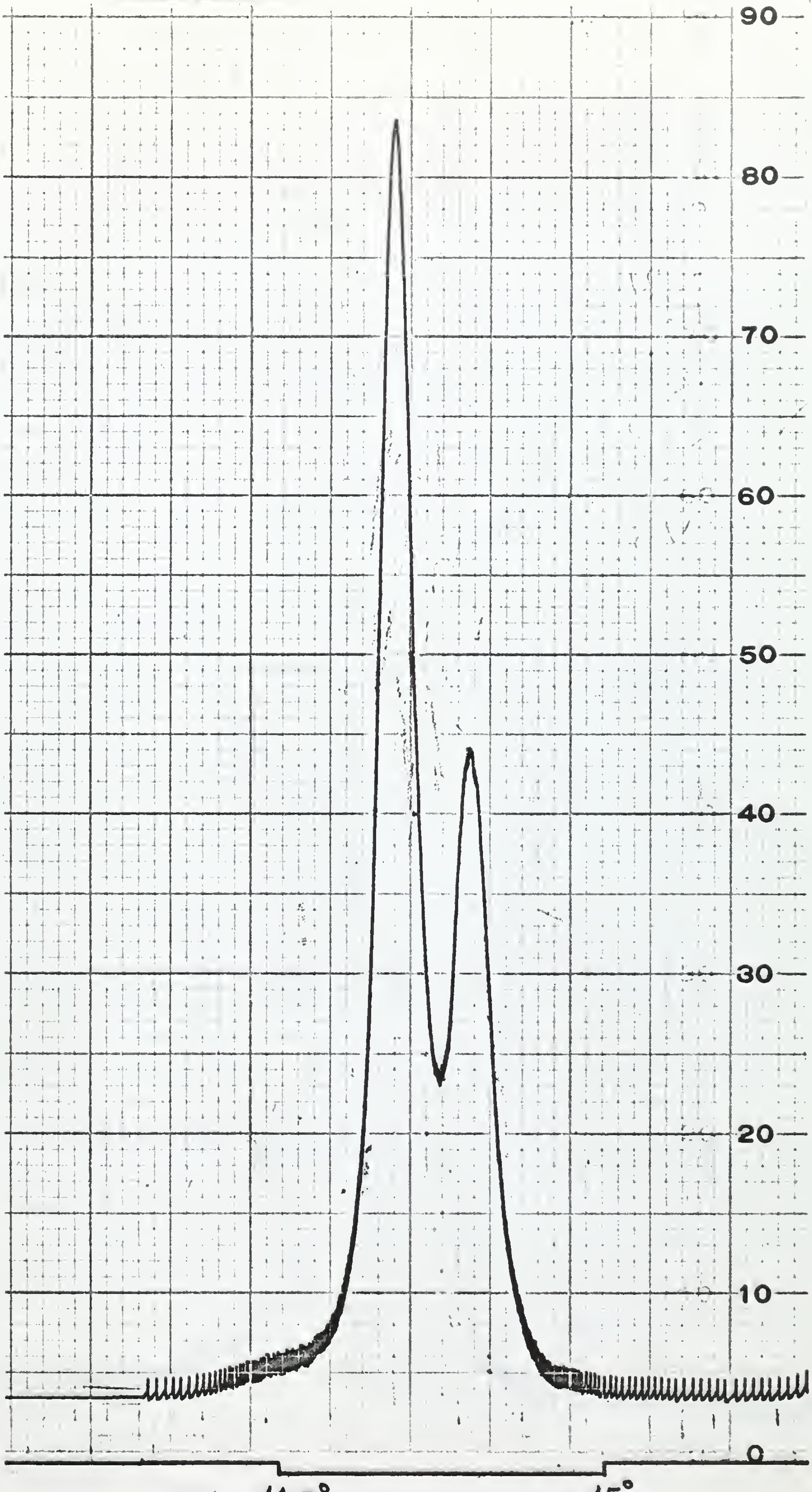

Fig. 20. Reference Peak, Pure Aluminum

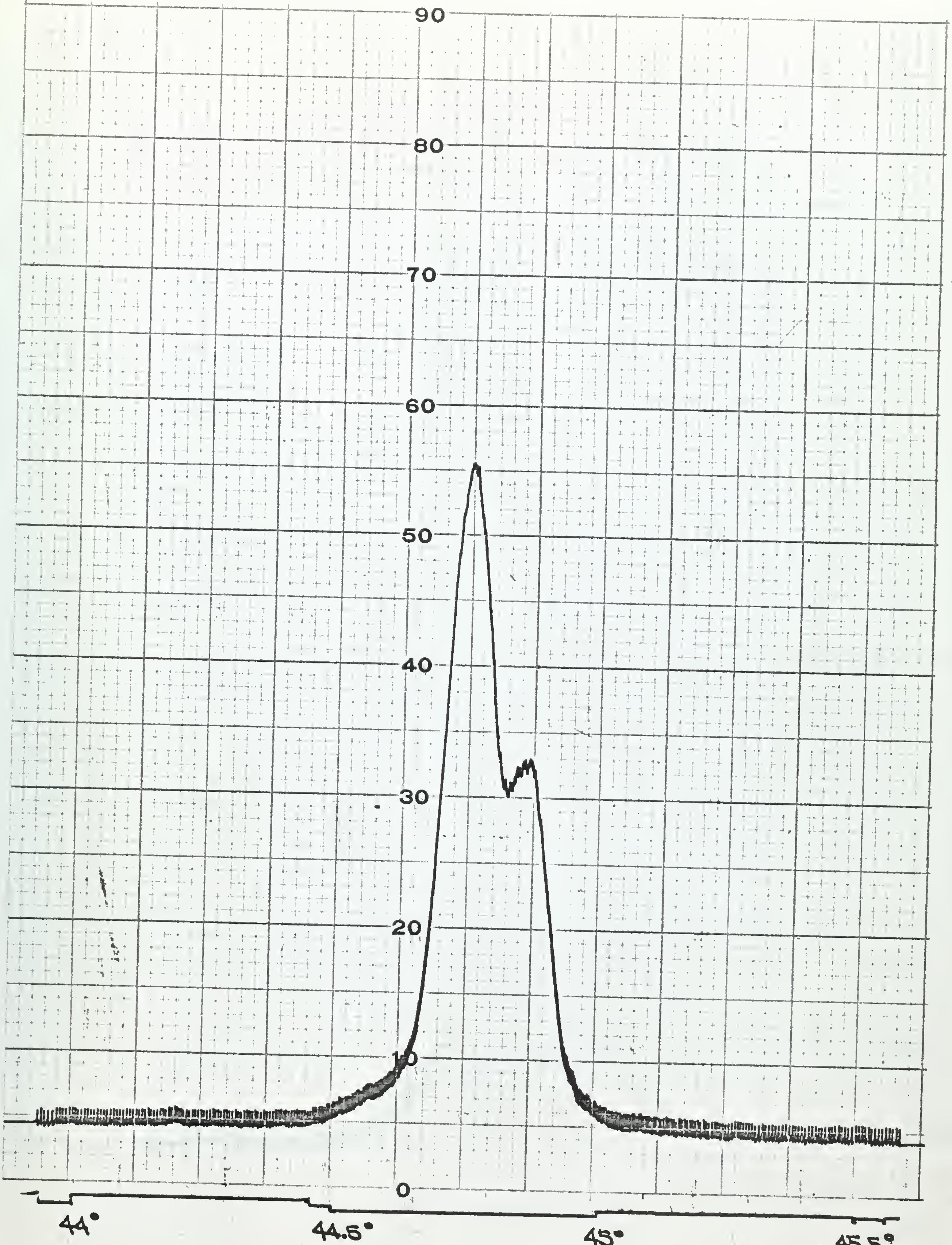

Fig. 21. As Quenched

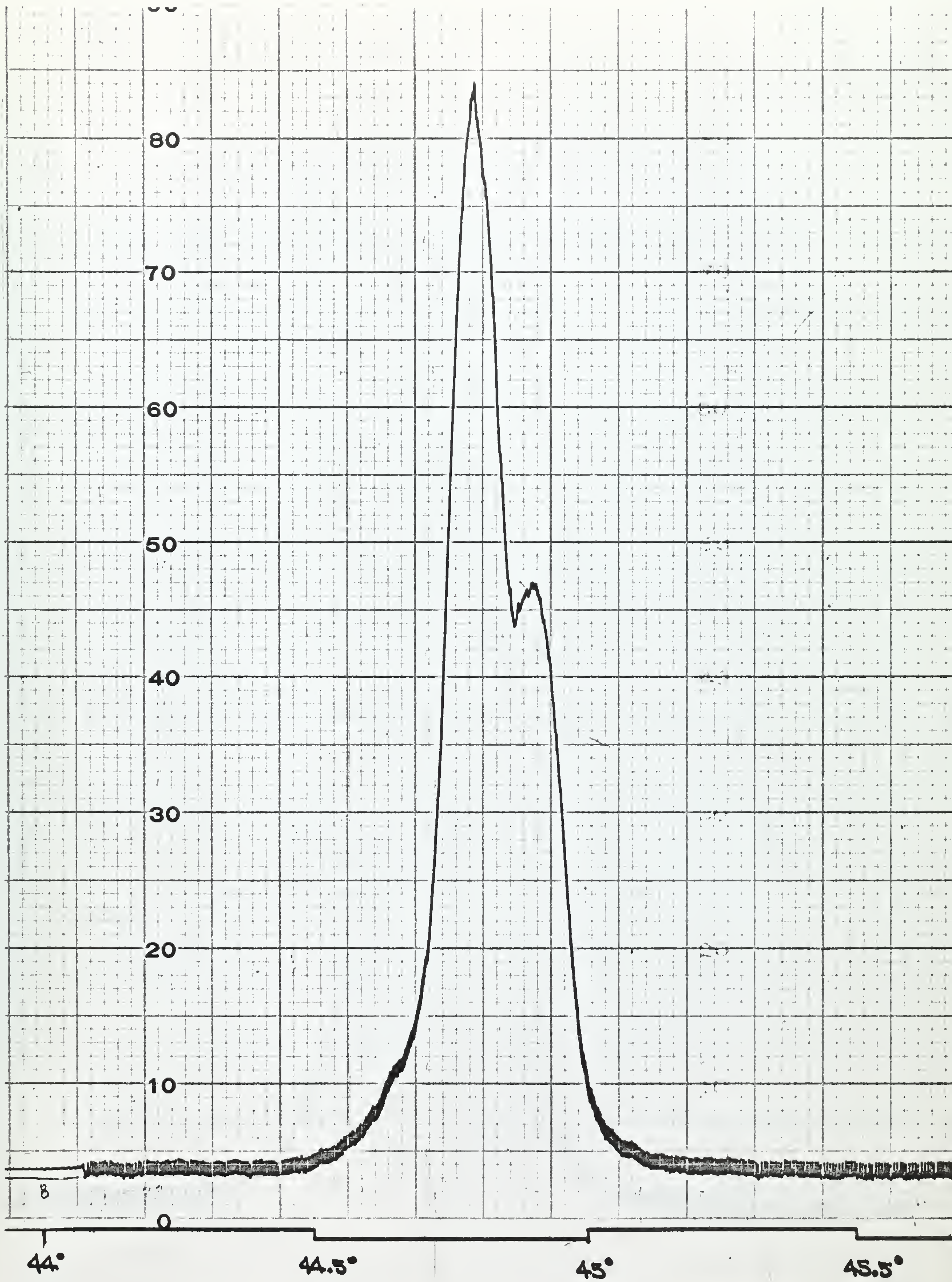

Fig. 22. Aged 65 days, Room Temp.

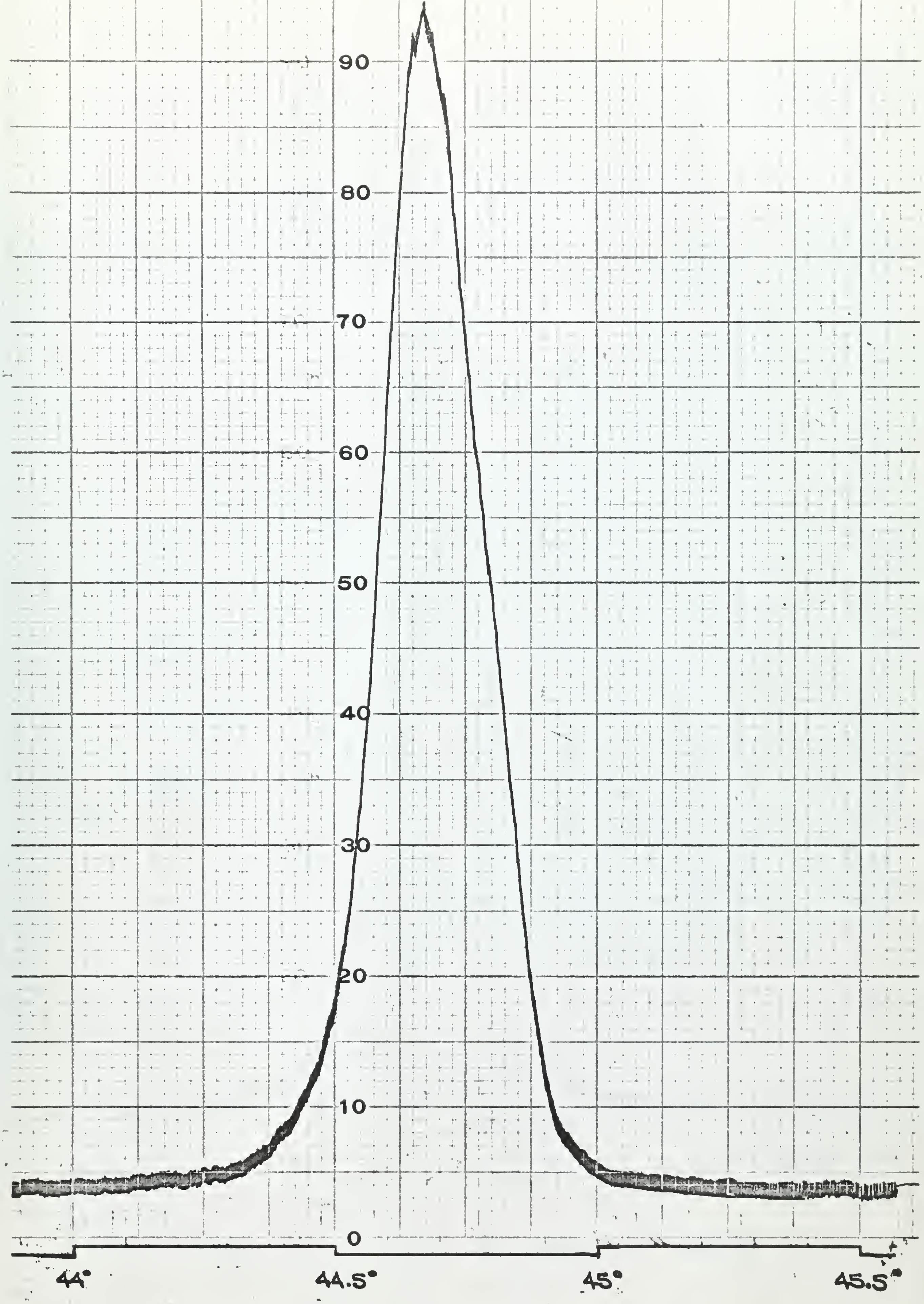

Fig. 23. Aged 1 day at 165°C

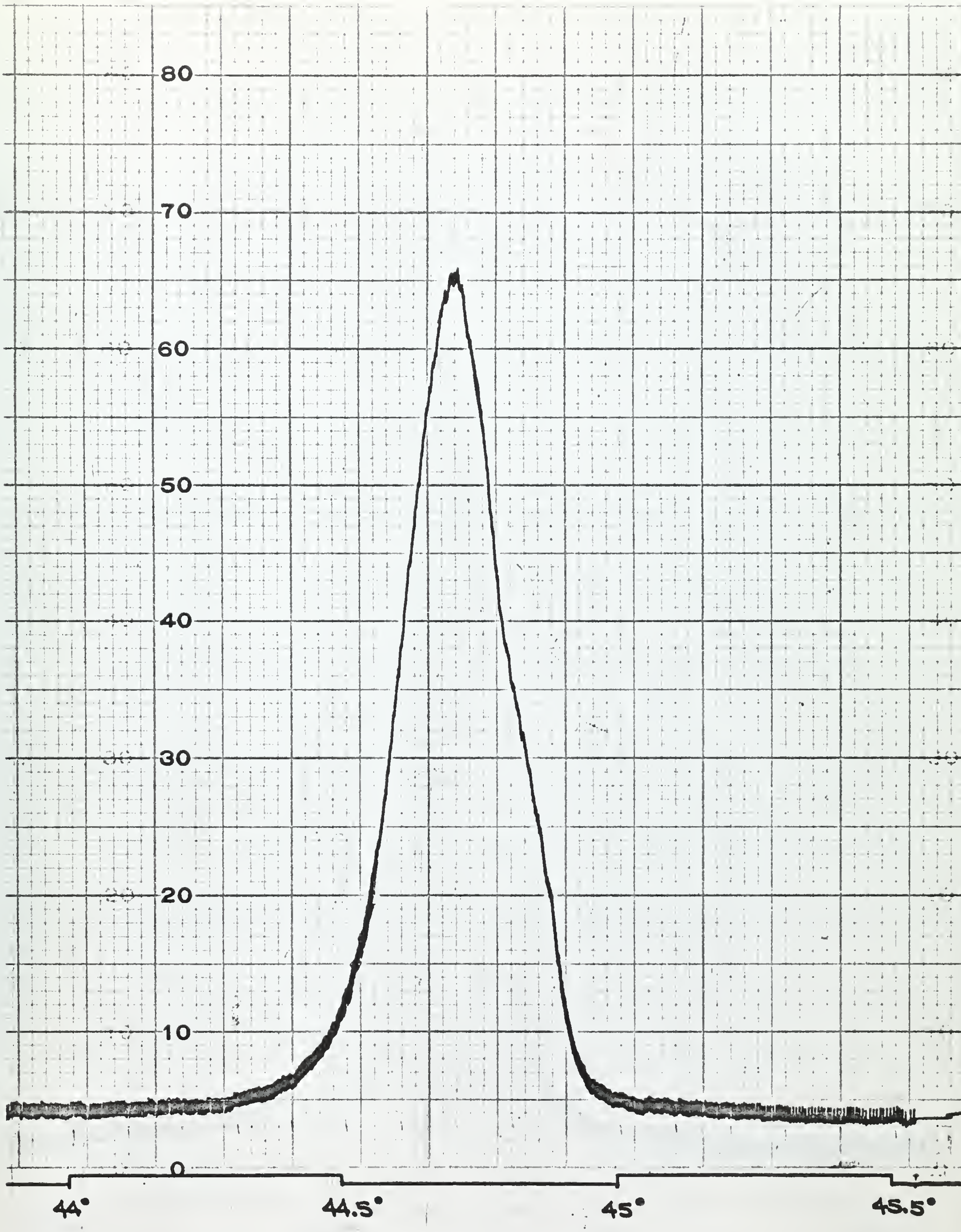

Fig. 24. Aged 2 days at 165°C

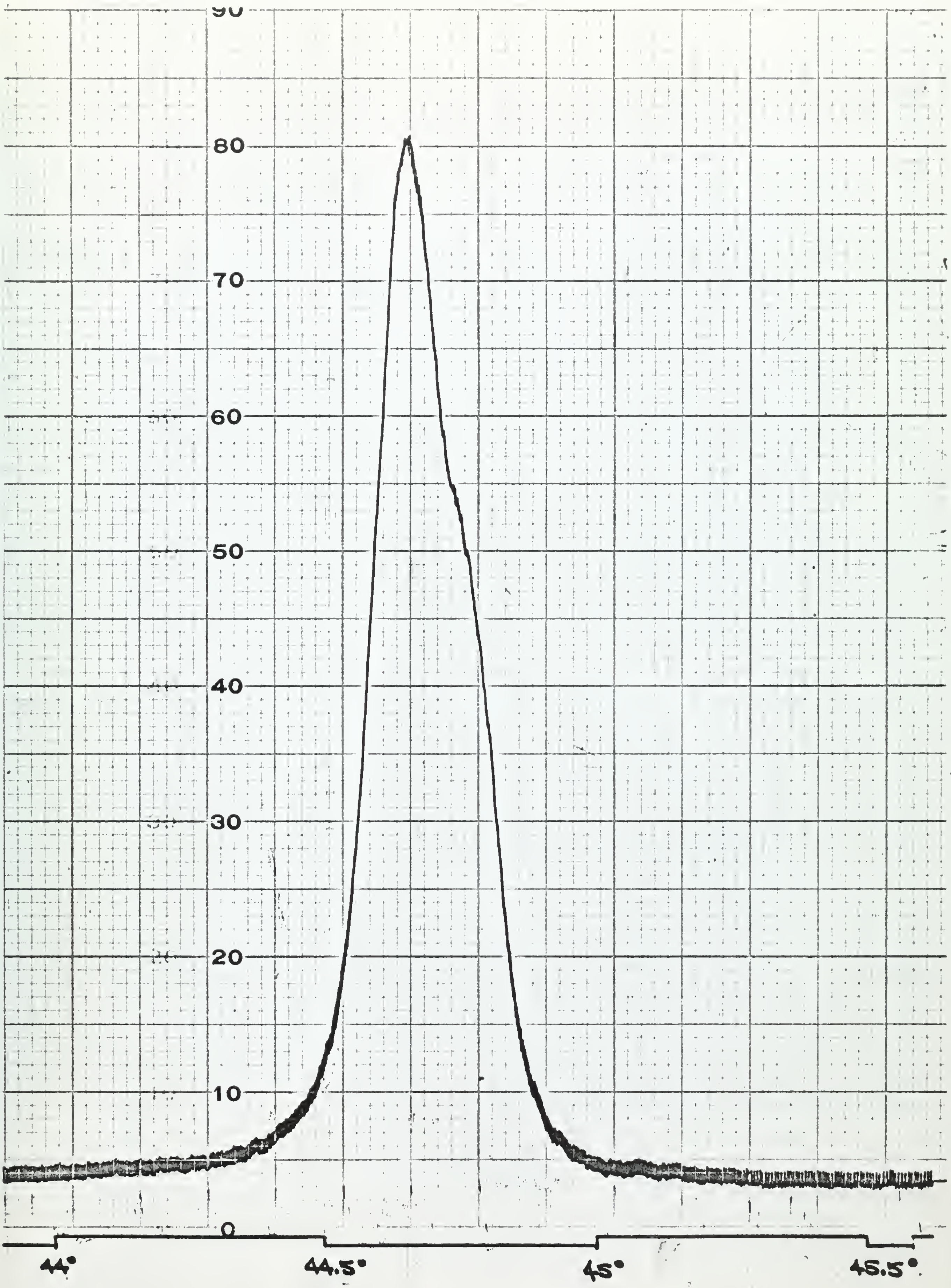

Fig. 25. Aged 5 days at 165°C

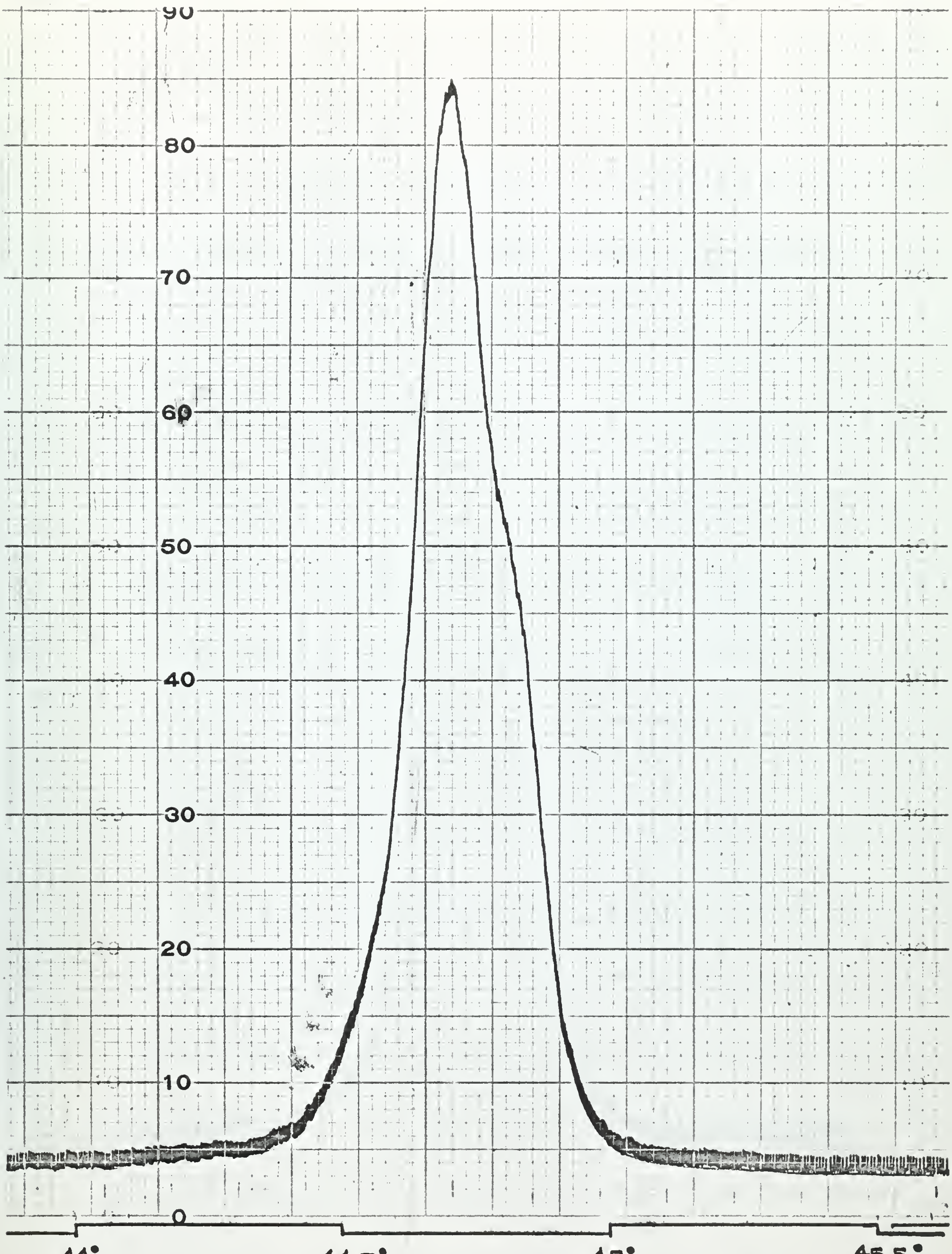

Fig. 26. Aged 9 days at 165°C

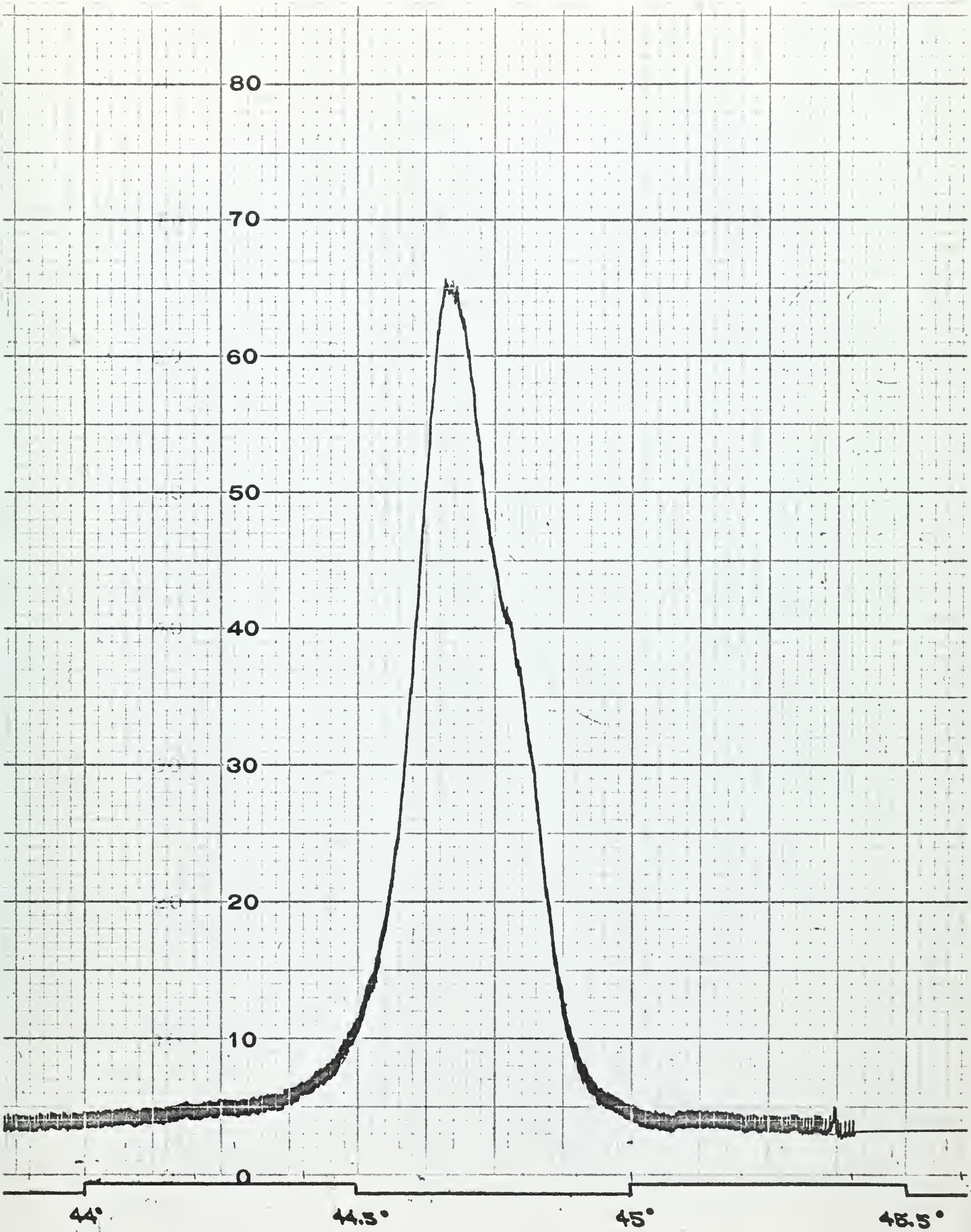

Fig. 27. Aged 14 days at 165° C

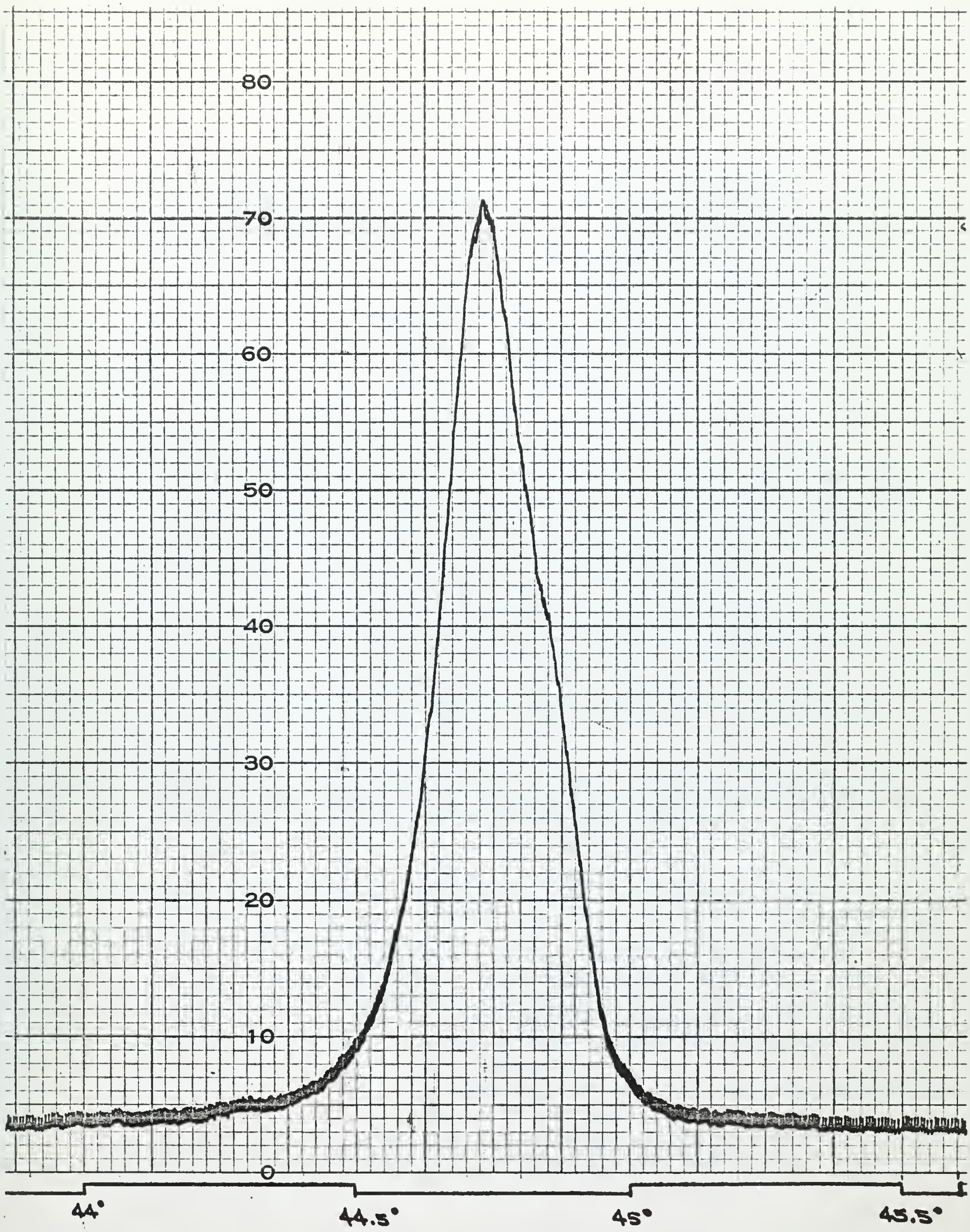

Fig. 28. Aged 30 days at 165° C

APPENDIX IV

THE FOLLOWING IS A FORTRAN 60 COMPUTER PROGRAM THAT WILL PERFORM THE STOKES UNFOLDING AND PATTERSON FUNCTION SYNTHESIS.

```
      PROGRAM  UNFOLD
C
C
C   THIS PROGRAM WILL COMPUTE
C     1. THE FOURIER COEFFICIENTS A(N,1) AND B(N,1) OF A CURVE
C     2. THE FOURIER COEFFICIENTS A(N,2) AND B(N,2) OF A SECOND CURVE
C     3. THE FOURIER COEFFICIENTS A(N) AND B(N) OF THE UNFOLDED CURVE 2/1
C     4. THE INVERSE FOURIER TRANSFORM (SYNTHESIS) OF THE UNFOLDED CURVE
C     5. THE CENTER OF GRAVITY OF THE UNFOLDED CURVE
C     6. THE LOCATION OF THE MAXIMUM IN THE UNFOLDED CURVE
C     7. A SERIES OF CURVES CAN BE SUCCESIVELY UNFOLDED
C     THE RESULTS CAN BE PRESENTED IN BOTH TABULAR AND GRAPHICAL FORM
C   GIVEN THE COEFFICIENTS IF(H,K,L)I**2, THE PROGRAM COMPUTES THE
C    PATTERSON FUNCTION, Y(U,V,W) (I.E. THE SUMMATION OVER THE COSINE
C    TERMS OF A FOURIER TRANSFORM OF I(F,(H,K,L)I**2 ).
C   THE RESULTS ARE PRESENTED AS ONE OR TWO DIMENSIONAL SECTIONS
C    ONE DIMENSIONAL SECTIONS CAN BE PRESENTED IN BOTH GRAPHICAL AND
C       TABULAR FORM
C    TWO DIMENSIONAL SECTIONS ARE PRESENTED IN TABULAR FORM
C   THE EXPERIMENTAL VALUES, IF(H,K,L)I**2 ARE CORRECTED FOR LORENTZ,
C    POLARIZATION, MULTIPLICITY AND TEMPERATURE FACTORS
C
C
C     FIRST DATA CARD CARRIES GENERAL TITLE - COLUMNS 2 - 80
C
C     SECOND DATA CARD
C                  COL 1-3  NA = 1 FOR THE FIRST CURVE OF A SET
C                              = 2 FOR THE SECOND CURVE OF A SET
C                  COL 4-5  NB = 0  IF FOLDING IS TO BE CALCULATED
C                              = 1 TO COMPUTE FOURIER COEFFICENTS ONLY
C                              A VALUE FOR NB MUST BE ENTERED OR STOP 15
C                              WILL RESULT.
C                              DIMENSIONS OF AA, BB, AND FIX DEPEND ON
C                              VALUE OF NA SPECIFIED
C                  COL 6-7  NC = +1  SYNTHESIS OF UNFOLDED DATA
C                              = -1  SYNTHESIS OF NEW DATA
```

```
C                 COL 8-9   ND = 0   NO GRAPH OF PATTERSON FN.
C                              = 1  GRAPH PATTERSON FN.  SEE BELOW.
C                 COL 10-74    TITLE OF UNBROADENED CURVE
C
C     THIRD DATA CARD - CONSTANTS FOR ANALYSIS OF UNBROADENED CURVE
C                            COL  1 -  5  N = NO OF INTERVALS
C                                 6 - 10  NCG = -1 FOURIER SYNTHESIS - GRAPH
C                                             =  0 NO SYNTHESIS
C                                             = +1 FOURIER SYNTHESIS
C                                11 - 15  MODE = 1 IMPUT DATA PRINTED
C                                             = 0 IMPUT DATA NOT PRINTED
C                                16 - 20  J - FIRST OUTPUT HARMONIC
C                                             (NORMALLY = 0)
C                                21 - 25  K - HARMONIC INCREMENT
C                                             (NORMALLY = 1)
C                                26 - 30  L- FINAL HARMONIC
C                                31 - 35  K2- SUB HARMONIC - IF 0, PROGRAM
C                                             SETS K2 = 1 .
C                                36 - 40  LC = 0  READS DATA CARD
C                                              MEMORY
C                                            = 1  USES DATA AVAILABLE IN
C                                41 - 50  THO =INITIAL TWO THETA
C                                51 - 60  THF = FINAL TWO THETA
C                                61 - 73  XL = WAVELENGTH
C
C     FOURTH DATA CARD - UNBROADENED CURVE,N EQUALLY SPACED POINTS FORMAT
C     (16F5.1) , ON THE NECESSARY NUMBER OF CARDS.
C
C     REPEAT SEQUENCE WITH A DUPLICTE GENERAL TITLE CARD , A SIXTH
C     CARD SETTING NA = 2 AND CARRYING A TITLE FOR THE BROADENED
C     CURVE , A SEVENTH CARD SETTING THE CONSTANTS FOR ANALYSIS OF THE
C     BROADENED CURVE ,AND AN EIGHTH CARD WITH  THE N POINTS OF THE
C     BROADENED CURVE.
C
C     FOR A GRAPH OF THE PATTERSON FN, FOLLOW THE TWO SETS OF DATA CARDS
C     (FOR THE REFERENCE AND BROADENED CURVES) WITH  TWO MORE CARDS.
C     THE FIRST ONE IS BLANK AND THE SECOND ONE SETS NA=NB=NC=0,  ND=1.
C
C         . FURTHER CONVOLUTIONS CAN BE CARRIED OUT WITH
C     ADDITIONAL SETS OF FOUR DATA CARDS , INCREASING NA BY ONE FOR
C     EACH FOLD UP TO 10.
C
C     ADDITIONAL CURVES CAN BE UNFOLDED BY ADDING ADDITIONAL SETS OF
C     DATA CARDS SETTING NA =1 AND 2 IN THE SECOND AND SIXTH CARDS OF
C     EACH SET
C
C     FOR A FOURIER ANALYSIS SET  NB = 1 IN COL 5 IN THE
C     SECOND CARD OF A SET OF DATA CARDS
C
```

```
C
C      THE PROGRAM IS TERMINATED BY TWO BLANK DATA CARDS
C
C
C      STATEMENT NUMBERS
C    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17
C   18   19   20   21   22   23   24   25   26   27   28   29   30   31   32   33   34
C   35   36   37   38   39   40   41   42   43   44   45   46
C        51   52   53
C   60   61
C                  103  104  105  106  107  108  109
C  110  111  112  113  114  115  116  117  118  119
C  120  121  122  123  124  125  126  127  128  129
C  130  131  132  133  134  135  136  137  138  139
C  140  141  142  143  144  145  146  147  148  149
C  150  151  152  153  154  155  156  157  158  159
C  160  161  162  163  164  165  166  167
C       501  502  503  504  505  506  507  508  509  510  511  512  513  514  515
C  900  901  902       904       906  907  908  909
C  47 48 49 70 170 71 72 73
C
C
C
    1 FORMAT (1H1////)
    2 FORMAT (80H0
     1                                                              )
   24 FORMAT (I5, 2F10.4, F10.5 , 2F10.4 ,F10.5 ,2F10.4, F10.5)
   39 FORMAT(I15,  2F15.4, F15.4//)
   40 FORMAT(1H013X1HN10X5HALPHA11X4HBETA6X 9HINTENSITY)
  900 FORMAT  ( I3, 3I2, 8A8)
  901 FORMAT(8I5, 3F10.3)
  902 FORMAT (16F5.1)
  904 FORMAT(3H0N=I4,  7H     J=I5,  7H     K=I5,  7H     L=I5,
     1  8H     K2=I5,7X6HNCG = I3///12H DATA POINTS//)
  906 FORMAT (1H0 16X 9HREFERENCE 20X 11HBROADENED   21X 9HCORRECTED //)
  907 FORMAT(1H0 4X 1HN 2X 5HALPHA 7X 4HBETA 3X 9HINTENSITY 4X 5HALPHA
     1 6X 4HBETA 2X 9HINTENSITY 4X 5HALPHA 6X 4HBETA 2X 9HINTENSITY//)
  908 FORMAT(1X)
  909 FORMAT(1X, 16F5.1)
C
C
      DIMENSION  Y(200), AA(200,4), BB(200,4), FIX(200,4), NAME(8),
     1 FR(200,4),  FI(200,4),  FIT(200,4),
     2  Z(1,1,900)
C
C
```

```
      DIMENSION  WW(900),   ITITLE(12)
      DO 71 I=1, 12
   71 ITITLE(I) = 8H
      ITITLE(1) = 8H LARSEN
      ITITLE(2) = 8H  0278
      ITITLE(7) = 8HPATTERSO
      ITITLE(8) = 8HN  FUNCT
      ITITLE(9) = 8HION  FOR
      ITITLE(10) = 8H  AL-CU
      LABEL = 4H 65D
C
      TPI = 6.28318530718
      R=1.0/(57.2957795131*2.0)
    3 READ 2
      READ 900, NA, NB, NC, ND, NAME
      IF(NC) 122, 15, 47
   47 IF(NA) 15, 15, 9
   15 IF (ND) 48,48,49
   49 CALL DRAW(101,Z,WW,0,0,LABEL,ITITLE,0,10.0,0,0,0,0,9,10,1,LAST)
      GO TO 3
   48 STOP 48
    9 READ 901, N, NCG, MODE, J, K, L, K2, LC, THO, THF, XL
      IF(K2) 30,31,30
   31 K2 = 1
   30 FN = N
      TNR = 2./FN
      THF = THF*R
      THO = THO * R
C     IF LC EQUALS ZERO, READ NEW DATA, OTHERWISE OPERATE ON OLD
      IF (LC) 32,33,32
   33 READ                 902, (Y(I), I= 1,N )
   32 PRINT 1
      PRINT 2
      PRINT 900, NA, NB, NC, ND,  NAME
      IF (MODE) 12,13,12
   12 PRINT 904,  N, J, K, L, K2, NCG
      PRINT 909, (Y(I), I = 1,N)
      IF (NA - 1) 515, 513, 514
  515 STOP 515
  513 AREA = 0.0
      DO 511 I = 1,N
      AREA1 =(Y(I)*(SINF(THF) - SINF(THO)))/ (XL * FN)
  511 AREA = AREA + AREA1
  514 DO 512 I = 1,N
  512 Y(I) = Y(I) / AREA
   13 XK2 = K2
      XJ = J
      ARG = TPI/FN/XK2
      ARG1 = ARG*XJ
```

```
      CS = COSF(ARG1)
      TCS = 2.*CS
      SS = SINF(ARG1)
      XK = K
      ARG2 = ARG*XK
      CB = COSF(ARG2)
      SB = SINF(ARG2)
      M1=J
      GO TO (501,502,503,504,505,506,507,508,509,510), NA
  501 NAN=NA
      GO TO 14
  502 NCW=NA
      NAN=NA-1
      GO TO 14
  503 NCW=NA-1
      NAN=NA-2
      GO TO 14
  504 NCW=NA-2
      NAN=NA-3
      GO TO 14
  505 NCW=NA-3
      NAN=NA-4
      GO TO 14
  506 NCW=NA-4
      NAN=NA-5
      GO TO 14
  507 NCW=NA-5
      NAN=NA-6
      GO TO 14
  508 NCW=NA-6
      NAN=NA-7
      GO TO 14
  509 NCW=NA-7
      NAN=NA-8
      GO TO 14
  510 NCW=NA-8
      NAN=NA-9
C     BEGINNING OF LOOP ON M1
   14 T3 = 0.
      T2 = 0.
       I =  N
   18 T1 = TCS * T2 - T3 + Y(I)
      I = I-1
      IF (I) 16,19,17
   16 STOP 16
   17 T3 = T2
      T2 = T1
      GO TO 18
   19 M=M1+1
```

```
      AA(M,NA) = (T1 - CS*T2)*TNR
      BB(M,NA) = (SS* T2)*TNR
      FIX(M,NA)=(AA(M,NA)*AA(M,NA) + BB(M,NA) * BB(M,NA))/TNR
C     TEST FOR END OF M1 SERIES
      IF(M1-L) 21,26,20
   20 STOP 20
   21 M1=M1+K
      TCS = CB*CS - SB*SS
      SS = CB*SS + SB*CS
      CS = TCS
      TCS = TCS + CS
      GO TO 14
   26 NO=NA-1
   11 IF(NO) 23,42, 27
   23 STOP 23
   42 IF(NB) 27,3,27
   27 PRINT 1
      PRINT 2
      L2=L+1
      J2=J+1
      IF(NB) 37,38,37
   37 PRINT 40
      PRINT 908
      DO 43  M = J2, L2
      M2=M-1
   43 PRINT 39,M2,AA(M,NA),BB(M,NA),FIX(M,NA)
      GO TO 3
   38 PRINT 906
      PRINT 907
      IF(NA-2) 22,22,28
   28 AA(M,NAN)=AA(M,NO)
      BB(M,NAN)=BB(M,NO)
      FIX(M,NAN) = (AA(M,NAN)*AA(M,NAN)+ BB(M,NAN)*BB(M,NAN))/TNR
   22 DO 25 M=J2,L2
      M2=M-1
      J2 = J + 1
      FR(M,NO) = (AA(M,NCW)* AA(M,NAN)+ BB(M,NCW)*BB(M,NAN))/FIX(M,NAN)
     1 *TNR
      FI(M,NO) = (BB(M,NCW)* AA(M,NAN)- AA(M,NCW)* BB(M,NAN))/FIX(M,NAN)
     1 *TNR
      IF(M -J2)46, 45, 46
   45 FA = FR(J2,NO)
   46 FR(M,NO) = FR(M,NO)/FA
      FI(M,NO) = FI(M,NO)/FA
      FIT(M,NO) =(FR(M,NO)*FR(M,NO) + FI(M,NO)* FI(M,NO))/TNR
      PRINT 24 ,M2,AA(M,NAN),BB(M,NAN),FIX(M,NAN) , AA(M,NCW), BB(M,NCW
     1) , FIX(M,NCW) ,FR (M,NO) , FI(M,NO) ,FIT(M,NO)
      IF(XMODF(M ,45))29,35,29
   35 PRINT 1
```

```
      PRINT 2
      PRINT 906
      PRINT 907
      GO TO 25
   29 IF(XMODF(M ,5))25,36,25
   36 PRINT 908
      GO TO 25
   25 CONTINUE
      IF(NCG) 122, 44, 122
C
C
C     PROGRAM FOUSYN
C
C
C     1ST DATA CARD
C       COL 1-80 TITLE
C
C     2ND DATA CARD
C       COL 1 - 4 DEBYE TEMP. B
C                    B=0.0 IF TEMP. FACTOR IS NOT COMPUTED
C           5 - 11 LAMBDA
C           11 - 14 NUMBER OF PEAKS USED
C       COL 15 - 20 NUMBER OF INTERVALS/CELL IN X DIRECTIONS
C           21 - 25 NUMBER OF INTERVALS/CELL IN Y DIRECTION
C           26 - 30 NUMBER OF INTERVALS/CELL IN Z DIRECTION
C
C     ADJUST DIMENSION STATEMENT FOR FRACTIONS UVW OF XYZ USED
C
C     3RD DATA CARD
C       COL 1 - 3 MAX VALUE OF U
C           4 - 6 MAX VALUE OF V
C     7 - 9 MAX VALUE OD W
C           10 - 12 MAX VALUE OF H
C           13 - 15 MAX VALUE OF K
C           16 - 18 MAX VALUE OF L
C           19 - 21 MAX VALUE OF U FOR PRINTOUT
C           21 - 23 MAX VALUE OF V FOR PRINTOUT
C           24 - 26 MAX VALUE OF W FOR PRINTOUT ACCORDING TO SECTIONS
C           WANTED
C
C     ADJUST DIMENSION STATEMENT FOR MAX VALUES OF HKL USED
C
C     4TH DATA CARD
C       COL 1 - 3 H
C           4 - 6 K
C           7 - 9 L
C           10 - 14 RELATIVE INTENSITY (WITH DECIMAL POINT)
C           15 - 18 TWO THETA
C           19 - 20 MULTIPLICITY
```

```
C
C
  122 CONTINUE
C
C
   51 FORMAT (3(3I3, F5.0, F4.0, I2, F5.0))
   52 FORMAT(F4.2,F7.5, I4, 3I5 )
   53 FORMAT (6I3, 3F4.2, 2F10.4)
    4 FORMAT (1H0,2X, 1HN, 6X, 22H(   U   ,   V   ,   W   )9X, 9H Y(U,V,W)
     1      //)
    5 FORMAT (I5, 6X, F6.4 , 1X, F6.4, 1X, F6.4, 6X, F12.4)
    6 FORMAT(50H                                                  )
    7 FORMAT (1X)
    8 FORMAT (1H1//// )
   60 FORMAT(21HOCENTER OF GRAVITY = F6.2)
   61 FORMAT (55HOMAX HARMONIC USED FOR SYNTHESIS OF CORRECTED CURVE =
     1  I3 //)
C
  167 DIMENSION F(1,1,500), TTH(1,1,500), MU(1,1,500), C3(100),
     1  S3(100),  F1(1,1,500),   C1(1),  C2(1),  S1(1),  S2(1)
C
      IF(NC) 129, 166, 128
  166 STOP 166
  129 READ 6
      READ 52,B,XL,NP,NU,NV,NW
      READ 53, J1, J2, J3, I1MAX, I2MAX, U3MAX, U1, V1, W1, TTHO, TTHF
      GO TO 136
  128 NN1 = 0
      NN2 = 0
      NU =  0
      NV =  0
      NW =   N
      J1 = 0
      J2 = 0
      J3 = 100
      J11 = J1 +1
      J22 = J2 +1
      J33 = J3 +1
      M2 = M - 1
      I1MAX = 0
      I2MAX = 0
      I3MAX = M2
      U1 = 0.0
      V1 = 0.0
      W1 = FN
      TTHO = THO
      TTHF = THF
  136 I1M = I1MAX + 1
      I2M=I2MAX+1
```

```
      I3M = I3MAX +1
      TTHD = TTHO - TTHF
      DO 115 I3=1,I3M
      IS3 = (I3 - 1)*100
      DO 115  I2 = 1, I2M
      IS2 = (I2-1)*10 + IS3
      DO 115 I1=1,I1M
      IS=IS2+I1
      F(IS)=0.0
      F1(IS) = 0.0
      TTH(IS)=0.0
      MU(IS)=0.0
  115 Z(IS)=0.0
      IF (NC) 127,  15, 126
  126 DO 137 M = 1, L2
      IF (M-1) 159,159,160
  159 I4M =0
  160 IF(I4M) 161,161,158
  161 F(1, 1, M) = FR(M, NO)
      F1(1, 1, M) = FI(M, NO)
      IF(FR(M, NO) ) 170, 170, 137
  170 I4M = M
      GO TO 137
  158 F(1, 1, M) = FR(M, NO)
      F1(1, 1, M) = FI(M, NO)
  137 CONTINUE
C        FOR TRY = -1.0,  Y(U,V,W) IS SYNTHESIZED USING THE FIRST M
C        HARMONICS THAT KEEP Y(U,V,W) POSITIVE.
  162 TRY = -1.0
      I3M = I4M -1
      I5M = I4M -2
      GO TO 125
C          FOR TRY = 1.0,   Y(U,V,W) IS SYNTHESIZED USING ALL  L HARMONICS.
  163 TRY = 1.0
      I5M = L2 - 1
      I3M = L2
      GO TO 125
  127 IF (XMODF(NP, 3))111, 112, 111
  112 NP = NP/3
      GO TO 113
  111  NP = (NP/3) + 1
  113 DO 114 NR = 1, NP
      READ 51, NN1, NN2, NN3, F(IS), TTH(IS), MU(IS), F1(IS)
      IS=NN3*100+NN2*10+NN1+1
      TTH(IS)=TTH(IS)*R
      AAA=SINF(TTH(IS))
      AAA2=AAA**2
      TE=1.0/EXPF(B*AAA2/XL**2)
      ZZ=COSF(2.0*TTH(IS))
```

```
      POL=(1.0+ZZ**2)/AAA2*COSF(TTH(IS))
      AMU(IS) = MU(IS)
      F1(IS) = F1(IS)/(TE * POL *AMU(IS))
  114 F(IS) = F(IS)/(TE * POL *AMU(IS))
  125 PRINT 8
      IF (NC) 131, 15, 130
  131 PRINT 6
      GO TO 132
  130 PRINT 2
      PRINT 61, I5M
  132 PRINT 4
      TPI=6.28318530718
      MARK=0
      IF(NC) 157, 138, 139
  138 STOP 138
  139 JU = 1
      JV = 1
      GO TO 140
  157 DO 104  JU = 1, J11
      DO 104 JV = 1, J22
  140 DO 104 JW = 1, J33
      IF(NC)153, 154, 155
  154 STOP 154
  155 U = 0.0
      V = 0.0
      GO TO 156
  153 AJU = JU - 1
      ANU = NU
      U = AJU/ANU
      AJV = JV - 1
      ANV = NV
      V = AJV/ANV
  156 AJW = JW - 1
      ANW = J3
      W = AJW/ANW
      IF(NC) 141, 142, 143
  142 STOP 142
  143 I1 = 1
      I2 = 1
      GO TO 144
  141 DO 103 I1=1,I1M
      DO 103 I2=1,I2M
  144 DO 103 I3=1,I3M
      NN1 = I1 - 1
      NN2 = I2- 1
      NN3 = I3 - 1
      FN1 = NN1
      FN2 = NN2
      FN3 = NN3
```

```
      IF (NC) 145, 146, 147
  146 STOP 146
  147 S1(I1) = 1.0
      S2(I2) = 1.0
      GO TO 148
  145 S1(I1) = SINF(U*FN1*TPI)
      S2(I2) = SINF(V*FN2*TPI)
  148 S3(I3) = SINF(W*FN3*TPI)
      TS = S1(I1) * S2(I2) * S3(I3) * F1(I1,I2,I3)
      IF (NC) 149, 150, 151
  150 STOP 150
  151 C1(I1) = 1.0
      C2(I2) = 1.0
      GO TO 152
  149 C1(I1) = COSF(U*FN1*TPI)
      C2(I2) = COSF(V*FN2*TPI)
  152 C3(I3)=COSF(W*FN3*TPI)
      T=C1(I1)*C2(I2)*C3(I3)*F(I1,I2,I3)
      IF (I3 -1) 117, 116, 117
  116 TSM=0.0
  117 TSM = TSM + T + TS
  103 Z(JU,JV,JW)=TSM
  107 MARK = MARK +1
      JJW = JW - 1
      PRINT 5, JJW, U,V,W, Z(JU, JV,JW)
      WW(JW) = JJW
      IF (XMODF (MARK, 35)) 109,108,109
  108 IF (NC) 134, 15, 133
  134  PRINT 8
      PRINT 6
      GO TO 135
  133 PRINT 8
      PRINT 2
  135 PRINT 4
      GO TO 165
  109 IF (XMODF (MARK , 5)) 165,110,165
  110 PRINT 7
  165 CONTINUE
  104 CONTINUE
      IF (TRY)  72,44,44
   44  GO TO 3
   72 IF (ND)  163,163,73
   73 CALL DRAW(101,Z,WW,0,0,LABEL,ITITLE,0,10.,0,0,0,0,6,10,1,LAST)
      GO TO  163
      END
      END
```

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